A REVIEW OF FOLIAR FERTILIZATION OF SOME VEGETABLES CROPS

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ABSTRACT

The main aim of this review is to analyze the state provide an overview of the foliar fertilization studies in Bulgaria, comparing them with the latest current research trends and to indicate future benefits of foliar nutrient spray investigations and their importance for agronomic science and practice.

The application of foliar sprays is an important crop management strategy in which may help maximizing crop yield and quality. Foliar fertilization is used as a means of supplying supplemental doses of macro- and micro-nutrients, plant hormones, stimulants, and other beneficial substances. Observed effects of foliar fertilization have included yield increases, resistance to diseases and insect pests, improved drought tolerance, and enhanced crop quality. Plant response is dependent on species, fertilizer form, concentration, and frequency of application, as well as the stage of plant growth.

Foliar applications are often timed to meet the demand of nutrients at specific vegetative or fruiting stages of growth, and the fertilizer formula is adjusted accordingly. Applications may also be used to aid plants in recovery from transplant shock, hail damage, or the results of other weather extremes. It is proposed that this treatment should be recommended in the integrated plant production, because it is more environmentally friendly and increases productivity and yield quality.

In the present paper, a short historical brief review of research on foliar fertilization, the advantages of foliar application of fertilizers, foliar fertilization on some vegetables in Bulgaria are discussed. It is concluded that foliar fertilization has a definite place in vegetables crop productions and that foliar nutrient sprays will be widely used in the future.

Keywords: foliar fertilization, vegetables, biological behaviors, yield, productivity
1. INTRODUCTION

During the last years there is a steady trend to reduce the use of mineral fertilizers, specially soil applied such as nutrients - nitrogen (N), phosphorus (P) and potassium (K) (Kerin and Berova, 2003). Their use has actually decreased to 7 times, which may even limiting the possibilities for realization of the basic soil fertilization requirements (Kerin and Berova, 2003). These facts create preconditions to increase the importance of foliar fertilization as an alternative to meet plant nutrient demand during the growing season. Interest on foliar fertilization has raised as a result of many advantages of the methods of application of foliar nutrients, such as rapid and effective response to plant needs, regardless of soil conditions (Kerin and Berova, 2003). Additional foliar application during the growth and development of crops can improve their nutrient balance, which in will lead to an increase in yield and quality (Kolota and Osinska, 2001).

According Fageria et al. (2009), interest in foliar sprays increased because of the development of high concentration soluble fertilizers and the development of machinery for spraying fungicides, herbicides, and insecticides and overhead irrigation further facilitate the application of nutrients to crops in the form of sprays. Advances in agriculture include reducing the cost of crop production costs, maintaining soil quality, increasing of agro-ecosystems, human, and animal health, use of nutrients in adequate amounts and its methods of application associated with these objectives (Kannan 2010). Kannan (2010) noted that foliar fertilization sprays cannot substitute soil fertilization in all cases, but that they can be used as supplement of soil applications and can be used in sustainable crop production.

In a recent review, Fernandez Fernandez and Eichert (2009) state that foliar fertilization is an agricultural practice of increasing importance in practical terms. In theory, application of nutrient sprays may indeed be an environmentally friendly fertilization method since the nutrients are directly delivered to the plant in limited amounts, thereby helping to reduce the environmental impact associated with soil fertilization. However, response to foliar sprays is often variable and not reproducible due to the existing lack of knowledge of many factors related to the penetration of the leaf-applied solution (Fernández and Eichert, 2009).

The main aim of this review is to analyze the state of the foliar fertilization studies in Bulgaria, comparing them with the latest research trends and to indicate future benefits of investigations and their importance for agronomic science and practice.

2. A SHORT HISTORICAL REVIEW OF RESEARCH ON FOLIAR FERTILIZATION

A historical overview of the development of foliar uptake basic and applied research studies was provided by Fernandez Fernandez and Eichert (2009). The first written
evidence of the ability of leaves to absorb water from the environment is from the second half of the XVII century. The absorption of nutrient elements from water solutions applied on the leaves and their physiological effect of the plant for the first time was the subject of researches in XIX century yet. The first reports for foliar feeding are in France during 1844 year. After these first publications, numerous other studies give reason of the success of foliar fertilization. At the same time has been described the structure of the leaves. Attention has been paid to the cuticle and its properties. It has been investigated leaf gas exchange, transpiration, nutrition assimilation, leaf anatomy and physiology (Fernandez-Fernández and Eichert, 2009). In the XX century, studies related to the principles and mechanisms of foliar application continue. They are aimed at clarifying the movement of water and dissolved substances in its leaves and the whole plant, using techniques with specific dyes. The role of stomata in the process of absorbing solutions was determined. Effect of adding surfactants to aqueous solutions was evaluated. The using of radioactive isotopes was enabled new stimulus to research on acceleration and movement of mineral nutrients in plants. New scientific information about the chemical composition and structure of the cuticle and the attention of environmental factors is obtained. Trials to identify the effects on microorganisms, leaf growth and synthesis of wax coating are conducted. The present research is focused on the physiological and agronomic aspects of the use of fertilizers for foliar application (Fernandez-Fernández and Eichert, 2009). In recent time, the researches are purpose on physiological and agronomic aspects of the use of fertilizers for foliar application (Fernandez and Eichert, 2009).

According to Tukey and Morczynski (1984), Doring and Gericke (1986), a combined soil and foliar applications should be recommended to increase both plant productivity and yield quality. Mc Call (1980), Lovatt (1999) and Kuepper (2003) pointed out that foliar application of fertilizers is becoming more prevalent as practice in agriculture—agricultural crop production, because comparison to soil fertilization it is more purposefully, and potentially more friendly to the environment in contrast to soil fertilization.

As noted by Wojcik (2004) knowledge on nutrient absorption mechanisms by above-ground plant parts is crucial to optimize foliar fertilization. These mechanisms are the basis for obtaining broad information about the relationship between growing of plants and the absorption of nutrients and ongoing physiological processes. Other main factors influencing relevant for successful foliar application are environmental conditions, properties and quality of the solutions as well as some biological characteristics related to specific botanical species and varieties, structure, size, morphology of leaves, nutrient balance of plants and phase of development (Fernandez-Fernández and Eichert, 2009; Wojcik, 2004).
3. ADVANTAGES OF FOLIAR APPLICATION OF FERTILIZERS

Foliar fertilization has in several main advantages. It can be applied throughout the growing season, which enable to spray with small quantity and composition of the nutrient solution, appropriate to the specific requirements in different phases of the crop development (Mc Call, 1980, Taiz and Zeiger, 1998; Lovat, 1999; Kueperr, 2003; Kerin and Berova, 2003; Fernández-Fernández and Eichert, 2009, Kannan, 2010).

Foliar applications may sometimes facilitate to the rapid absorption of mineral elements, avoiding the occurrence of soil interactions that may limit root uptake due to e.g., nutrient immobilisation in the soil. In these nutrients, they can not be immobilized remain unavailable for root uptake. Additionally, foliar fertilisation may stimulate the capability of root system for better absorption of nutrients from the soil solution is stimulated (Mc Call, 1980, Taiz and Zeiger, 1998; Lovat, 1999; Kueperr, 2003; Kerin and Berova, 2003; Fernández and Eichert, 2009, Kannan, 2010).

Nutrient uptake via the foliage may be much faster as compared to soil nutrition (Weinbaum, 1988; Kueperr, 2003; Kerin and Berova, 2003; Lester et al, 2006; Fernández-Fernández and Eichert, 2009, Kannan, 2010).

With the use of fertilizers for foliar nutrient applications can very quickly be eliminate correct physiological dysfunction of plant diseases disorders caused by the deficiency or lack of a particular nutrient deficiencies, as well as help to overcome various stress conditions (Franke, 1986; Pavlova et al., 1986, Taiz and Zeiger, 1998, Kerin and Berova, 2003, Kueperr, 2003).

Fernández-Fernández and Eichert, (2009) point out noted that one of the traditional applications of foliar application is to correct nutritional deficiencies in plant organisms. According to Kannan, (2010) foliar fertilization can include in the technology of growing of different vegetables.

Fertilizers successfully mixed with most commercial pesticides used in practice and in many cases may often improve the mixing efficiency of the performance of foliar fertilization-fertilizers, and increase enhance the activity-effectiveness of pesticides hence used and lets to reducing plant protection e the costs of treatment plants (Pavlova et al., 1986, Witek 2000; Kueperr, 2003). In this regard are investigations of Nowosielski (1994) and Nowosielski et al (1998), which explored the possibilities a foliar application like practice of as tool for integrated pest management for the production of vegetables.

In most cases foliar fertilizers are 100% water soluble. They do not contain impurities that could damage plants, and lead to the accumulation of toxic residues in the productions (Kerin and Berova, 2003; Kueperr, 2003). Alexander and Schroeder (1987),
Fageria et al. (2009) and Kannan (2010) indicate the great potential of foliar fertilization as a means of reducing soil and ground water pollution of soil and water.

Jaskulski (2007) shows the positive economic effect of foliar fertilization in growing vegetables like the practice, having a direct impact on increasing yield. Confirmation of the economic viability of foliar application is also demonstrated by Kostadinov and Borisov (2007) and Sarkar et al. (2008).

Despite all the advantages of foliar application of fertilizers, some authors such as Fageria et al. (2009) and Kannan (2010) draw attention to the possibility of causing damage to the leaf injury and even more serious damage to plant damage when not all requirements for solutions after foliar spraying are applied.

El-Fouly (2002) pointed out that many new applications of foliar fertilizers have been recommended and implemented in the practical agriculture and horticulture. This development encouraged the progressive production of foliar fertilizers in many countries for local use as well as for export. There is a real chaos in the market. For example in Egypt, during the period 1990 – 1995, 554 new fertilizers were registered. Out of them 285 are indicated as foliar fertilizers and over two hundred soluble fertilizers for drip irrigation, which are partially used as foliar fertilizers. Quality control of foliar fertilizers is a much more difficult issue than quality control of soil used fertilizers. The efficiency of foliar fertilizers is depending on much more different measures than soil fertilizers, thus agreeing on quality criteria are much more complex.

According El-Fouly (2002) most countries do not have special articles regulations in their legislation specifically related to foliar fertilizers and thus, there are no special quality criteria for this kind of fertilizers. It is could be highly recommendable that to study the situation and legislation in some developed and developing countries and to make proposals specific suggestions about the quality criteria, which should be considered for the registration of foliar fertilizers in different regions, and which that should be made clear to the customers.

Pavlova and Michailova (2009) considered foliar fertilization as an integral part of the whole system for feeding plants. They point out, that foliar application not to oppose their not an alternative to soil fertilization, but that. The application of foliar sprays supplied may be useful to supply part of the necessary nutrients and stimulate nutrient absorption by the function of the root system. It is submitted that the nutrients in the leaves for a short time move and reach the smallest root branching. In this regard, the authors Pavlova and Michailova (2009) claim that foliar application may changing change broadcast the concentration of some metabolites in the root zone, and consequently help to improve the solubility of the mineral substances elements in the soil.
These conclusions are in agreement with the results of Fageria et al (2009), who show the large effect of foliar application of relatively small amounts of macro- and micro-nutrients on plant productivity, which was due to the increased physiological activity of roots.

4. FOLIAR FERTILIZATION ON SOME VEGETABLES: CASE OF BULGARIA

In Bulgaria, at the beginning of the 1970's liquid fertilizers of the Wuksal series (8%N, 8%P₂O₅, 6%K₂O, 0,004%Cu EDTA, 0,02%Fe EDTA, 0,012%Mn EDTA, 0,01%Mo EDTA and 0,004% Zn EDTA; Aglukon Ltd., Germany) were used. Their application was limited to field production of tomatoes and peppers, and of green-house production of tomatoes and cucumbers (Rankov et al., 1998). The good results motivated for the development and production of liquid fertilizers of the Bulgarian series Fixal (9%N, 9%P₂O₅, 7%K₂O and micro element 0,004%Cu EDTA, 0,02%Fe EDTA, 0,012%Mn EDTA, 0,01%Mo EDTA and 0,004% Zn EDTA; Sipro Treiding Ltd., Bulgaria) and Laktofol (21%N, 5%P₂O₅, 10%K₂O, 0,020%B, 0,014%Cu, 0,250%Fe, 0,002%Mn, 0,002%Mo and 0,018% Zn; Ekofol AD., Bulgaria) and their recommendation and use in agricultural production (Rankov 1992).

Pavlova and Michailova (2009) summarized the results of twenty years of research on foliar fertilizers in Bulgaria. The foliar fertilizer Laktofol (21%N, 5%P₂O₅, 10%K₂O, 0,020%B, 0,014%Cu, 0,250%Fe, 0,002%Mn, 0,002%Mo and 0,018% Zn; Ekofol AD., Bulgaria) proved effective in terms of helping to increase growers economic returns, reduced soil contamination and contributed to lowering of soil applied fertilizer concentrations hence contributing to the rational use of fertilizers.

At the same time, the use of foliar fertilizers reduced chemical contamination of soil and - due to agricultural production, in Growing some vegetables, it is found that the use of Laktofol (21%N, 5%P₂O₅, 10%K₂O, 0,020%B, 0,014%Cu, 0,250%Fe, 0,002%Mn, 0,002%Mo and 0,018% Zn; Ekofol AD., Bulgaria) can reduced soil fertilization rates. The less studied are: There is less information available on the effect of the foliar fertilizers Fitona (7.20%N, 5.20%K₂O, 1.5%Ca, 0.9%Mg, 0.1%Fe, 0.1%B, Cu, Zn, Mn, Mo; Fitotech Ltd., Bulgaria) and Hortigrow (20%N 20%P₂O₅, 20%K₂O, 0.06%Fe, 0.02%Zn, 0.01%Mn, 0.01%Cu, 0.02%B, 0.001%Mo and 1% amino acids, Hortiland Ltd., Nederland). — They are mineral products containing pure, highly concentrated nutrients with added amino acids and phytohormones. Kostadinov (2009) study the influence of Fitona (7.20%N, 5.20%K₂O, 1.5%Ca, 0.9%Mg, 0.1%Fe, 0.1%B, Cu, Zn, Mn, Mo; Fitotech Ltd., Bulgaria) and Hortigrow (20%N 20%P₂O₅, 20%K₂O, 0.06%Fe, 0.02%Zn, 0.01%Mn, 0.01%Cu, 0.02%B, 0.001%Mo and 1% amino acids, Hortiland Ltd., Nederland) on biological behaviors on eggplant. The author demonstrates that the combined soil and foliar applications affects vegetative habits,
productivity and physiological status of the treated plants. These results give proof of the use of foliar application of eggplant as an environmentally friendly decision—crop fertilization strategy to the fertilization of the crop, citing achieved leading to positive economic and environmental effects of its use.

The foliar fertilizer Hortigrow (20% N, 20% P₂O₅, 20% K₂O, 0.06% Fe, 0.02% Zn, 0.01% Mn, 0.01% Cu, 0.02% B, 0.001% Mo and 1% amino acids, Hortiland Ltd., Nederland) has been studied in pepper with is another other economically important vegetable crop in Bulgaria—pepper. Panayotov (2004) tested different doses of foliar fertilizer on vegetative development and productivity of pepper. He found that its use increases plant productivity and improves product quality. Effect achieved is due to the harmonious-balanced development of vegetative growth in plants. With increasing dose of Hortigrow, the effect on vegetative growth decreased, but remains higher than in untreated control plants.

Panayotov and Stoeva (2005) studied the effect of Hortigrow (20% N, 20% P₂O₅, 20% K₂O, 0.06% Fe, 0.02% Zn, 0.01% Mn, 0.01% Cu, 0.02% B, 0.001% Mo, 0.014% Cu, 0.25% Fe, 0.02% Mn and 0.018% Zn; Hortiland Ltd., Nederland) on some physiological parameters in pepper. Presented Their results showed that spraying the plants with Hortigrow induced significant changes in leaf gas exchange, the content of plastid pigments and intensity of photosynthesis.

The aim of the experimental work carried out by Al-Humrani (2009) was to establish analyse the influence of foliar fertilization with Laktofol (21% N, 5% P₂O₅, 10% K₂O, 0.02% B, 0.014% Cu, 0.25% Fe, 0.002% Mn, 0.002% Mo and 0.018% Zn; Ekofol AD., Bulgaria), Hortigrow (20% N, 20% P₂O₅, 20% K₂O, 0.06% Fe, 0.02% Zn, 0.01% Mn, 0.01% Cu, 0.02% B, 0.001% Mo and 1% amino acids, Hortiland Ltd., Nederland), Agroleaf (20% N, 20% P₂O₅, 20% K₂O, 0.14% Fe DTPA, 0.07% Zn EDTA, 0.07% Mn EDTA, 0.07% Cu EDTA, 0.03% B, 0.001% Mo; Scotts Company, Nederland) on the feeding, growth and productivity of radish, and also searching for opportunities to optimize nutrient conditions supply. It was found that twice use of fertilizers has clearly expressed influence on the physiological condition of the plants. Their use as part of the agricultural production activities in the cultivation of radish, could be achieved amany increase in the yield and quality of standard products with high quality horticultural commodities.

Doykova and Rankov (1995) investigated the effectiveness of foliar Laktofol "O" (21% N, 5% P₂O₅, 10% K₂O, 0.02% B, 0.014% Cu, 0.25% Fe, 0.002% Mn, 0.002% Mo and 0.018% Zn; Ekofol AD., Bulgaria) in zucchini squash variety Biserka (Cucurbita pepo L. var. giromontia). The Researchers found that the investigational levels of mineral fertilization: 0, 8, 12, 16 kg N, P₂O₅ and K₂O, in a 1:1:1 ratio with foliar fertilizer suspension Laktofol "O" (21% N, 5% P₂O₅, 10% K₂O, 0.02% B, 0.014% Cu, 0.25% Fe, 0.002% Mn, 0.002% Mo and
The highest additional increase in yield (14.2%) with the lowest rate of NPK was determined. When decreasing ratio of NPK with 25% and 50% crop yield and vegetative mass decreased. However, in foliar fertilization, differences between yields of plants fertilized with N\textsubscript{16}P\textsubscript{16}K\textsubscript{16} and those with reduced rates NPK are statistically unproven.

In From 1996 to 1997, Doykova and Rankov (1997) investigated the influence of foliar fertilizer Laktofol "Fe" (17%N, 8.5%K\textsubscript{2}O, 2.8%MgO, 0.020%B, 0.010%Cu, 1.3%Fe, 0.010%Mn, 0.001%Mo and 0.007% Zn; Ekofol AD., Bulgaria) under field conditions on the variety Biserka (Cucurbita pepo L. var. giromontia) and fertilization with 0, 8 and 16 kg N, P\textsubscript{2}O\textsubscript{5} and K\textsubscript{2}O in the ratio 1:1:1 with and without foliar application. The results indicate that the highest yield is obtained by fertilization with N\textsubscript{16}P\textsubscript{16}K\textsubscript{16} + Foliar feeding - 7.059 kg da\textsuperscript{-1} or 41.3% more than in control – non fertilized. The effect of foliar application was significantly higher for 50% reduction in standards of NPK. Interesting from an economic point of view is the option that is conducted only foliar application. Individual application of the foliar fertilizer also increases the yield. The good results are probably due to the fact that when spraying with Laktofol, zucchini are better developed and provided a more assimilates of growing fruits.

The results of Doykova and Rankov (2002) led them to conclude that foliar feeding with Laktofol "O" (21%N, 5%P\textsubscript{2}O\textsubscript{5}, 10%K\textsubscript{2}O,0.020%B, 0.014%Cu, 0.250%Fe, 0.002%Mn, 0.002%Mo and 0.018% Zn; Ekofol AD., Bulgaria) and Laktofol "Fe" (17%N, 8.5%K\textsubscript{2}O,2.8%MgO, 0.020%B, 0.010%Cu, 1.3%Fe, 0.010%Mn, 0.001%Mo and 0.007% Zn; Ekofol AD., Bulgaria) will help to reduce the rate of soil fertilization. This reduction may be in the range of 20-25%. Thereby, foliar fertilization proves useful to reduce chemical contamination of soil and for improving yields and increasing economic returns associated with the rational use of fertilizers.

Along with complex water-soluble mineral fertilizers, the use of organic fertilizers with high content of humic and fulvo acids is gaining scientific importance. There is an increasing interest for many Bulgarian and foreign authors to investigate the response of plants when treated with fertilizers containing potassium humate (Demir et al., 1999; Petkova and Poryazov, 2007; Yildirim, 2007). All authors indicated that treatment with fertilizers containing humic acids leads to growth promotion accelerates the development of plants, increased yield and enhanced quality of crops.

In Bulgaria, in the last years there is a significant tendency towards increasing the interest towards assessing the performance of products based on humic acids, especially potassium humate. Many researchers conducted experiments to establish the impact of humic fertilizers on biological behaviors of many crops. In the vegetable species of particular
interest is foliar fertilizer Humustim (3%N 1.14%P₂O₅ 7.83%K₂O 3.92%Ca, 1.1%Mg, Cu, Zn, Mo, Co, B, S. Agrospeis Ltd., Bulgaria), which influence on the growth and productivity is studied in plants - Brussels sprouts and garden beans Petkova and Poryazov (2007), on the onions Bileva and Babrikov (2007); on the tomatoes Dincheva et al. (2009), on the lettuce Neykov et al. (2009), Petkova and Boteva (2007) reported that obtained yield of zucchini squash variety Izobilna after treatment with Humustim (3%N, 1.14%P₂O₅, 7.83%K₂O, 3.92%Ca, 1.1%Mg, Cu, Zn, Mo, Co, B, S. Agrospeis Ltd., Bulgaria), increased by 16-29.78% compared to control, and mass of fruit in 6.6-7.4%. Our studies show that the use of complex organic fertilizer containing humic acids Humustim (3%N 1.14%P₂O₅ 7.83%K₂O 3.92%Ca, 1.1%Mg, Cu, Zn, Mo, Co, B, S. Agrospeis Ltd., Bulgaria), stimulated the vegetative growth, increased the total yield of zucchini and improved fruit quality (Haytova, 2009; Haytova, 2013a; Haytova, 2013b).

The literature review outlines a clear tendency of increasing the growing interest in foliar fertilization as a method of stimulating the biological potential of the vegetables crops. After research apart from analyzing the fundamental mechanisms of absorption of nutrients through the leaves and determining the advantages and disadvantages of foliar fertilization, the efforts of researchers on these problems more often research efforts are directed to solving specific problems in individual vegetables with the science-based recommendations.

The current interest in foliar fertilization can be illustrated by the ongoing several research studies carried out with number of vegetable crops such as: pepper - Baloch et al. (2008), Maheswari and Haripriya (2008) and Karakurt et al. (2009), Hussein et al. (2012); lettuce – Dimitrov et al. (2005); head cabagge – Atanasova et al. (2007); melons - Kosterna et al. (2009); tomato - Premesekhar and Rajashe, (2009) and Ejaz et al. (2012); green beans - Fawzy et al. (2010) and Borowski and Michalek (2011); carrots - Smolen and Sady (2009) and Poberezynt et al. (2012); Onion - Charbaji et al. (2008); eggplant - Azarpour et al. (2012); Peas - Gad El-Hak et al. (2012) okra - Mondal et al. (2012) Cucumber - El-Nemr et al. (2012)

5. CONCLUSION

In conclusion, summary, it may be noted that As of this moment there is a significant trend towards expansion of the assortment of introducing new foliar fertilizer commercial products for foliar fertilization. In the agro-chemical catalogs and product lables are indicated the recommended rates of application, which are suggested as universal according to the principles of foliar fertilization and arbut may not be consistent with the specific characteristics of the vegetables and growing seasons. This information is not sufficient for realization to ensure positive biological and economic effects after the application of foliar fertilizers.
It is not well known the effect of different foliar fertilizers on the potential responses to the treatments such as vegetative behaviors of vegetable species, growth, their overall productivity and yield, market and biological value of production cannot be predicted.

In this regard, to optimize plant responses to foliar nutrient sprays, future further research on foliar fertilization of vegetable crops should continue to be carried out in the future. They could be used to such studies may include foliar fertilization as part of a growing technology for a more sustainable and environmentally friendly vegetable production. Yields will be increased under terms potentially environmentally friendly.

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