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SULPHUR AS A DEFICIENT ELEMENT IN AGRICULTURE – ITS INFLUENCE ON YIELD AND ON THE QUALITY OF PLANT MATERIALS

SIARKA JAKO PIERWIASTEK NIEDOBOROWY W ROLNICTWIE – ROLA W PLONOWANIU I WPŁYW NA JAKOŚĆ SUROWCÓW ROŚLINNYCH

Abstract: Sulphur plays a special role in plant metabolism. It takes part in protein synthesis and sugar metabolism and influences the quantity and quality of fat in seeds, the quality of wheat flour, the value of hay as fodder, and the taste and smell of onion and garlic. Because of its functions in the life of plants, sulphur can be included alongside nitrogen, phosphorus and potassium as a nutrient determining crop yield and quality. The role of sulphur in plant nutrition has gained importance in the last 10–15 years, when this nutrient was found to be deficient in plant production in most European countries, including Poland. This was mainly due to the reduction in emissions of sulphur compounds to the atmosphere and in the amount of sulphur entering the soil with mineral and natural fertilizers. This element's functions and its increasingly severe deficiency in the growth environment of plants indicates that sulphur should be considered alongside other nutrients in determining the fertilization requirements of crop plants.

Keywords: source of sulphur, sulphur in plants, quantity of plants, quality of plants, sulphur as a deficient nutrient

Introduction

Sulphur has long been known to be an essential nutrient for the proper development of living organisms. In considering the quantitative nutrient requirements of plants, sulphur is usually placed fourth, after nitrogen, potassium and phosphorus [1].

Sulphur plays a special role in the metabolism of plants. It is a component of many important compounds whose deficiency leads to disruptions in plant development [2–5].

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In spite of its importance, until the early 1980s little attention was given to sulphur in European countries. It was not a subject of interest in agricultural research, nor was it taken into account in determining the fertilization requirements of plants. This was due to the fact that on most of the continent the sulphur balance was positive. The main contributor to this positive balance was SO_2 emitted into the atmosphere during burning of fuels, particularly hard coal, brown coal and petroleum. Significant amounts of sulphur also entered the soil with certain mineral fertilizers [1, 6–8].

Excessive emissions of sulphur compounds had a negative influence on ecosystems and on the quantity and quality of plant materials [9–11]. The damage was so great that numerous measures were taken to reduce the amount of sulphur oxides in the atmosphere. These measures were so effective that SO_2 emissions were reduced by 40–60 % in most countries [12].

Unfortunately, the reduced amounts of sulphur present in the atmosphere and entering the soil with mineral fertilizers led to sulphur deficiencies in plant production [4, 6, 7, 13–16].

There are many indications that in some regions of Poland the sulphur balance in the soil may be negative as well. Studies by IUNG, Pulawy assessing the amount of sulphur in our country's soils suggest that this element may be lacking in the growth environment of plants [15]. These data show that in over half of soils (53 %) the supply of sulphur available to plants is low (less than 20 mg $S–SO_4 \cdot kg^{-1}$), in 26 % average, and in 16 % high. The remaining 5 % are soils polluted due to human activity. Deficiency of this nutrient can be expected mainly in lighter, usually acidified mineral soils, situated far from industrial centres [3, 8, 12].

Sulphur deficiencies, as a new problem in agriculture, become apparent mainly in crops whose demand for this nutrient is high, and are manifested as a decrease in yield (by as much as 50 %) and lower quality of agricultural produce [1, 6, 7, 17].

The aim of this study is to assess the role of sulphur as a deficient nutrient in determining the yield and quality of crop plants. The assessment will be made on the basis of data from the literature and in part on the authors' own research.

Sulphur sources in agrosystems

The primary sources of sulphur in the soil are minerals. The most important of these are gypsum ($CaSO_4 \cdot 2H_2O$), iron sulphides (FeS and FeS_2), hydrotroilite ($FeS \cdot nH_2O$), sphalerite (ZnS), chalcopyrite ($CuFeS_2$), cobaltite (CoAsS), sodium aluminium sulphate ($NaAl(SO_4)_2 \cdot 12H_2O$), tamarugite ($NaAl(SO_4)_2 \cdot 6H_2O$), iron sulphate ($FeSO_4$), potassium sulphate ($K_2SO_4$), sodium sulphate ($Na_2SO_4$), and magnesium sulphate ($MgSO_4$), as well as compounds in a lower oxidation state, such as sulphites, thiosulphites, pentathionates and elemental sulphur [9, 17].

Most sulphur, however, occurs in the form of organic compounds and is a component of humus. The remaining organic compounds enter the soil together with plant and animal residues and microorganisms. Dominant among these are the following:

– amino acids, especially methionine and cysteine,
– peptides (glutathione),

– proteins,
– sulpholipids,
– vitamins – thiamine and biotin [2, 9, 15].

Sulphur also enters the soil with certain mineral fertilizers. These can contain chemically diverse forms of sulphur, so that their assimilability varies considerably [1, 7, 8, 13, 16, 18, 19].

The mineral fertilizers which introduce the greatest amounts of this element into the soil are ammonium sulphate (240 kg S · Mg^{-1}), potassium sulphate (180 kg S · Mg^{-1}), single superphosphate (120 kg S · Mg^{-1}), gypsum or phosphogypsum (180–190 kg S · Mg^{-1}), magnesium sulphate (130 kg S · Mg^{-1}), kieserite (220 kg · S Mg^{-1}) and elemental sulphur [1, 11, 13, 15].

Certain amounts of sulphur can also enter the soil with natural fertilizers, especially manure, in which the sulphur content ranges from 0.3 to 0.6 kg S · Mg^{-1} [1, 13, 17, 20].

In recent years the amount of sulphur entering the soil in the form of mineral and natural fertilizers has undergone a marked decrease. This problem concerns not only Poland, but some other European countries as well. In Denmark, for example, 34 kg S · ha^{-1} · $year^{-1}$ entered the soil with these fertilizers from 1970 to 1975, but only 20 kg S by 1994 [7, 14, 15, 20]. In Poland, with the current level of mineral fertilization and assortment of mineral fertilizers used, about 10 kg S · ha^{-1} · $year^{-1}$ are estimated to enter the soil in this way. The amount of sulphur introduced into the soil by manure should be added to this figure.

Certain amounts of sulphur can make their way into the soil from the polluted atmosphere through dry deposition or wet deposition [1, 7, 9, 17]. Dry deposition occurs when SO_2 is absorbed on the soil surface in gas form, and then dissolved and oxidized in the soil solution. Sulphur oxides can also be oxidized to sulphuric acid in the atmosphere and make their way into the soil with rain or other precipitation. Then we are dealing with acid rain [3, 10, 21]. The main source of SO_2 emissions is electricity production, which is responsible for nearly 57 % of all sulphur oxides emitted into the atmosphere. When industrial power and systems for supplying heat to the household and public sector are taken into account, the figure reaches nearly 95 %.

Compared with 1980, when annual sulphur oxide emissions in Poland reached 4132 thousand metric tonnes (ie Mg), a marked decrease has been noted [8, 11, 12, 20]. A major reason for this was the Oslo Protocol signed in 1994, under which Poland committed itself to limit its SO_2 emissions to 1397 thousand metric tonnes by 2010.

In western and northern Europe, a decrease in sulphur oxide emissions took place as early as the early 1980s [4, 16]. A significant reduction of SO_2 in the atmosphere in Europe resulted from the Helsinki Protocol signed in 1985, under which the signatories committed themselves to reducing emissions of sulphur compounds by 30 % by the end of 1993. Further decisions required that by 2003 reduction of SO_2 emissions would reach 60 % [6, 16].

Some authors [9], however, emphasize that in spite of the significant decrease in SO_2 emissions, they are showing a clear tendency to rise again. According to these authors, the main reason for this tendency is the overly energy-intensive structure of our economy and the high share of hard coal and brown coal in the country's fuel-energy balance.

Sulphur uptake mechanism

Plans take up sulphur through their roots, mainly in the form of SO_4^{2-}. Certain amounts of the element can also be absorbed by leaves in the form of SO_2 [2, 11, 17, 22].

The sulphate uptake mechanism can be passive or active. The passive process is physicochemical, mainly taking place through diffusion, and consists in an equalizing of concentrations between the external solution and the apparent free space in the root. Sulphates within this space are not bound and can be exchanged for other ions or removed by scrubbing. The active sulphur uptake process can take place against the concentration gradient and requires energy expenditure by live cells [2, 17].

Sulphur can also be taken up by plants in the form of SO_2 [1, 17]. Of the total sulphur content in plants, the proportion which is taken from the air depends on how well-supplied they are with this nutrient. On average the proportion is taken to be 15–30 % in plants well-supplied with sulphur, and more than 50 % in plants suffering from a deficiency of this element. From these data it can be concluded that sulphur contained in the air cannot be a sufficient source of this nutrient for plants.

Sulphate uptake depends on many external factors. One of these is ion concentration [3, 8, 11, 13, 23]. The higher the concentration of SO_4^{2-} ions in the external environment, the greater their uptake by plants. Of course this effect has limits, depending largely on the species of plant cultivated. After these values are exceeded, further increases in sulphate ion concentration no longer affect how quickly the ions are taken up by plants.

The presence of other ions in the plant growth environment can also affect sulphur uptake. Nitrogen and phosphorus play an indirect role resulting from the fact that in determining crop yields, they also increase the need for other nutrients, including sulphur [7, 8, 24, 25].

Calcium and magnesium ions, on the other hand, cause a marked decrease in sulphur content in plants [1, 26, 27]. In experiments with meadow grasses and maize, the authors cited demonstrated a 5–25 % decrease in sulphate content in plants fertilized with magnesium chloride. A similar tendency was observed after soil liming with dolomite.

A marked antagonism was also observed between the uptake of selenates and sulphates [28]. This dependency occurs in higher plants as well as in algae and fungi. In the case of higher plants, however, sulphates are taken up more intensively than are selenates.

The rate of sulphate uptake also depends on the vegetative stage of the plant. Generally most of the sulphur is taken up during the period before blooming [4, 13, 20]. During later developmental stages the percentage content of sulphur in the plants decreases. This is due to a rapid increase in dry plant weight and a decrease in the rate of sulphur uptake.

Sulphur requirements of plants

The sulphur requirements of plants depend mainly on its species and on crop size [4, 6, 13, 15, 17, 20, 29, 30]. Sulphur demand in particular plant species is generally similar to phosphorous demand. Grasses, however, and thus grains and maize as well, take up less sulphur than phosphorus; the Fabacae take up similar amounts; while the Brassicaceae and the Liliaceae take up more sulphur than phosphorus.

Crop plants can be divided into three groups according to their sulphur requirements [9, 11, 17]:

I. Plants with very high sulphur demand. This group consists mainly of the Brassicaceae, such as rapeseed, mustard, radish and turnip, and the Liliaceae, such as onion and garlic. These plants produce specific sulphur compounds which determine their quality characteristics, such as fatty acids, mustard oil, and others. With an average yield they take up 40 or even 80 kilograms of sulphur from 1 ha. Plants belonging to this group respond to an addition of sulphur to their environment with a marked increase in yield [6, 8, 15, 18, 22, 29, 31, 32].

II. Plants with high sulphur demand. These include mainly the Fabacae, particularly alfalfa and clover, which produce significant amounts of protein, as well as maize and beets, due to the quanity of biomass produced. In the case of the Fabacae, their high sulphur requirements are also the result of symbiosis with bacteria binding nitrogen from the air [4, 13, 17].

III. Plants with relatively low sulphur demand. The nutritional requirements of this group of plants range from 12–25 kg of sulphur from 1 hectare. This group includes various grass species as well as potatoes. In these plants, even in soil very rich in sulphur there is generally no response to fertilization with sulphur alone. However, when they are fertilized with high levels of other nutrients, particularly nitrogen and phosphorus, causing yields to rise, there may be an increase in sulphur demand and in the response to sulphur added to the growth environment [7, 15, 25].

Symptoms of sulphur deficiency in plants

External symptoms of sulphur deficiency are difficult to identify. In many cases they are nearly identical to those of nitrogen deficiency [1, 6, 8, 13, 17, 33]. The only difference is that lack of nitrogen first manifests on older leaves, which yellow and then dry up, while with sulphur deficiency the yellowing appears on younger leaves and apical meristem. Typical symptoms of sulphur deficiency in the growth environment of plants are small, light green leaves and shortened and narrowed leaf veins, somewhat lighter than the tissue between the veins.

In some plants, such as rape, swede, and turnip, along with yellowing there appears a characteristic curling of the leaf blade to form a spoon shape [2, 8].

Under conditions of sulphur deficiency plants also produce less chlorophyll, and if the deficiency is severe, chloroplast disintegration occurs in their assimilative organs [5].

Other symptoms can be observed when sulphur is lacking in the growth environment of plants, such as changes in leaf and stem colour and improper development of some organs [6, 17]. Numerous studies of rape, which is particularly sensitive to sulphur deficiency, have found growth to be inhibited in plants living in conditions where this nutrient was lacking. When stem or leaf growth is inhibited, plants are undergrown and the surface area of the leaf blades decreases, reducing the assimilative surface. Plant habit is altered as well, as stem thickness growth is inhibited. As sulphur deficiency becomes more severe, the leaves and stems because stiff and brittle [2, 17].

Similar dependencies have been found in studies by these authors on direct and secondary effects of sulphur fertilization and liming on crop yield [34]. From observations made during vegetation it can be concluded that one of the factors inhibiting the development of the Brassicaceae and grain species studied was sulphur deficiency in their growth environment. The Brassicaceae (rape, mustard plant) had altered plant habit and numerous deformations, while the grains (especially spring barley) had markedly lower propagation rates and produced fewer ears than plants whose fertilization included sulphur.

Influence of sulphur on crop yield

Sulphur is a nutrient which plays a major role in determining crop yield. Its deficiency generally leads to lower yields, particularly in plants that are highly sensitive to lack of sulphur in their growth environment. Reduced yields can also result from direct and indirect effects of sulphur compounds emitted into the atmosphere in large quantities [9, 10, 16, 20].

Numerous experiments conducted in Great Britain, Ireland and many other countries indicate a marked increase in the yield of crops fertilized with sulphur [4, 6–8, 15, 16, 18, 31, 32, 35, 36]. This is particularly true of rape and of grasses cut several times a year.

The results of field experiments conducted with various plants in Great Britain indicated that sulphur fertilization increased rape yield by 10–327 %, while in the case of grasses cut several times a year the increase in biomass produced was 5–134 % compared with the control [1, 5, 13]. It should be noted, however, that the response of rape to sulphur fertilization varied considerably. In one of the experiments conducted in an industrial area of England, where the rape yield was 2 $Mg \cdot ha^{-1}$, application of 10 kg $S \cdot ha^{-1}$ led to a marked increase in yield, whereas in agricultural regions of Scotland with a yield of 3.5 $Mg \cdot ha^{-1}$ the maximum increase in seed yield was observed only after application of 32 kg $S \cdot ha^{-1}$. These observations showed that the optimal dose of sulphur, ensuring maximum winter rape yields, should be within a range of 20–30 kg $S \cdot ha^{-1}$ [13, 37]. Studies conducted in Poland have increasingly emphasized that the sulphur demand of the new, doubly-improved varieties of rape is 88 kg S where seed yield is 3.5 $Mg \cdot ha^{-1}$ [20, 30, 32].

Research by Withers et al [36] and Scherer [1] showed that grains, which have lower sulphur requirements, responded with a maximum yield increase to much lower doses of this nutrient. The optimal dose for barley was 10 kg $S \cdot ha^{-1}$ in the form of gypsum, while for wheat it should be about 20 kg $S \cdot ha^{-1}$. At this level of sulphur fertilization, the increases in grain yield for winter forms of wheat and barley were 4–18 %, while straw yield increased 1–16 %.

In the case of meadows cut several times a year, experiments conducted in Wales and in southwest England determined that the most effective dose was about 10 kg $S \cdot ha^{-1}$ for each cut [13]. Similar dependencies were found in other studies [6, 31, 38].

As in other countries, many studies have been conducted in Poland on the influence of sulphur on crop yield. One of the first of these was carried out in 1914 by Wróblewski, who used elemental sulphur in potato and rape cultivation [cited by 39]. Koter et al [40], in experiments using the isotope ^{35}S observed a marked increase in the vegetative mass of spring rape, oats and Swedish clover when sulphate concentration was increased. Goźliński and Grzesiuk [cited by 9], found in their experiments with maize that when sulphur is deficient there is no grain yield, because only rudimentary ears are formed. A similar response is found in beans, which do not form pods when sulphur is lacking.

Later, Benedycka [41] demonstrated the beneficial effects of sulphur fertilization (K_2SO_4) on common radish grown in light soil. Similarly, in an experiment with sunflower and seradella, Uziak and Szymańska [24] confirmed that applying sulphur to the growth environment was highly effective. In the case of sunflower, the positive effects of increased sulphur occurred following application of a higher level of NPK fertilizer, while for seradella, the higher sulphur dose negated the unfavourable effects of a large concentration of NPK on yield.

An excess of sulphur can also affect crop yield, but because sulphur is currently considered a deficient element in agriculture, the problem of excessive amounts of sulphur on cultivated plant yield will not be considered in this paper.

Distinct differences in growth and development were also observed between various species in a study conducted by these authors [34]. The greatest increase in yield resulting from application of sodium sulphate in the first year of the study occurred in the case of spring rape, spring barley and white mustard, while oats responded with the lowest increase. The least response to sulphur fertilization was observed in oats. This is closely correlated with the nutritional sulphur requirements of particular plant species.

The influence of sulphur on the quality of crops

In addition to the influence of sulphur on yield, emphasis has also been placed on its effects on the quality of plant material obtained [4, 6, 7, 13, 25, 32, 33, 42]. The main effect of sulphur deficiency is that it limits protein synthesis. The role of sulphur in the synthesis process consists of two fundamental functions:

1. Sulphur is an essential nutrient for the proper activity of enzymes involved in nitrate reduction, hence plants grown in conditions where this element is lacking accumulate nitrogen in non-protein form (nitrates, amides, and other compounds, such as ammonia).

2. Plants lacking sulphur produce lower-quality protein, with lower content of exogenic amino acids, particularly methionine and cysteine [2, 7, 9, 11, 17].

An insufficient supply of sulphur to plants also causes changes in sugar metabolism. A two- or threefold increase in starch content occurs, while at the same time the amount of reducing sugars decreases. This is mainly because of decreased photosynthetic activity in the plants due to chlorosis induced by the lack of sulphur [1, 11].

In oilseed crops, sulphur deficiency usually leads to decreased fat content in the seeds [6, 8, 9, 29, 32, 42]. This problem most severely affects rape. Sulphur strongly increases both this plant's yield and the fat content of its seeds. Experiments conducted by numerous authors [13, 37] show that a dose as low as 25 kg S · ha^{-1} causes an increase of about 20 % in the oil obtained from 1 hectare, compared with plants that were not fertilized with this nutrient.

Nevertheless, it is worth mentioning that in the opinion of some authors [5, 30, 42] increased accumulation of oil in rape seeds is accompanied by an increase in free fatty acid content, which results in significantly poorer quality of the oil. For this reason the amount of sulphur applied to the soil should be strictly correlated with the plants' demand for this nutrient. Exceeding the recommended amounts reduces the technological value of the oil by increasing its acidity [9, 13, 42].

Sulphur fertilization is also one of the most important factors affecting the synthesis and accumulation of glucosinolates in rape seeds [1, 6, 8, 13, 29, 32, 42]. Excessive amounts of these compounds negatively affect the quality of post-extraction ground meal so that it cannot be used as fodder. According to McGrath et al [13] about 25–30 % of the total amount of sulphur present in seeds occurs in glucosinolates, which negatively affects the taste of post-extraction ground grain and increases goitrogenic activity in animals.

Also very important in terms of quality of plant materials is adequate supply of sulphur to grains. Sulphur deficiency leads to reduced quality of wheat flour by negatively affecting its "baking value" [6, 13, 25, 27, 33]. This has to do with the positive correlation between sulphur content in flour and plasticity of dough [7, 13, 25]. This problem affects both conventional and organic agriculture, because substances enhancing the baking value of flour should not be added to organic products [6, 11].

Another negative effect of sulphur deficiency in the growth environment of plants is reduced fodder quality of hay [1, 6, 17, 31]. Sulphur deficiency increases nitrate concentration in meadow plants, while a high level of sulphur fertilization of grasslands leads to significant limitation of selenium intake by plants. Animals feeding on such fodder are less able to assimilate copper contained in it.

Seeds of plants from the Fabaceae family, which are a valuable source of protein for people and animals, also require proper levels of sulphur fertilization. When lacking in this nutrient, they produce protein with markedly lower content of sulphur amino acids, particularly methionine, which is one of the most valuable amino acids determining the nutritional value of plants [1, 13, 17].

The beneficial effects of sulphur on crop quality are also noticeable in the case of vegetable crops. The main benefits of sulphur fertilization of these crops are increased carotene content and improved taste and smell of onion and garlic [9, 22].

In studies conducted by these authors, application of sulphur in the form of Na_2SO_4 also had a marked effect on the quality of the species studied [43]. In the case of rape, an increase in fat content was observed, with a lower proportion of linolenic acid. This should be considered a beneficial characteristic, because too much of this fat accelerates the rancidity process. An unfavourable consequence of sulphur fertilization, in terms of the quality of edible vegetable fats, is the decreased proportion of linoleic acid observed in the seeds of plants fertilized with sulphur. In the case of white mustard seeds, application of sulphur had a relatively small influence on total fat content, but the quality of the fat obtained was noticeably improved. This was manifested as an increase in the proportion of oleic acid, and in some sites, of linolenic, myristoleic and palmitoleic acids. Higher content of these unsaturated acids in industrial fats improved their properties significantly. In the case of grain crops, the beneficial effects of sulphur fertilization was manifested as an increase in the percentage of valine in barley grain and of tyrosine and phenylalanine in oat grain.

Determining the level of nutrient supply in plants

In terms of yield and crop quality, it is very important to determine the level of nutrient supply. This also has great importance in examining economic and ecological aspects, because under conditions of optimal macro- and micronutrient supply, fertilization is highly effective and relatively small quantities of nutrients are transported outside the root system [1, 16, 17].

The most frequently used sulphur indicators in plants are total S content, N:S ratio, $S\text{-}SO_4$ content and the ratio of sulphates to total sulphur [1, 6, 7, 11, 13, 33, 37]. The choice of indicator should be determined mainly by the species of the plant whose sulphur supply is to be assessed. According to numerous authors [13, 25] the best indicator for determining sulphur supply in grasses is the N:S ratio. With optimal sulphur supply to this group of plants the ratio should be about 17:1. Other indicators, such as total sulphur content, sulphates, and total nitrogen, are highly variable during plant vegetation, and thus are less reliable in assessing the plant's supply of this nutrient. This view was supported by studies by Rasmussen, Spencer and Freney (cited in [13]), who suggested that the N:S and sulphate to total S ratios are constant throughout the vegetation period. Recently, however, it has been demonstrated that virtually all of the indicators used take on different values during different development stages of plants. This variability makes them difficult to use in assessing the sulphur nutrition status of plants [4, 11, 13].

The best indicator for winter rape harvested in the bloom stage is considered to be total S concentration, where the critical value indicating sulphur deficiency is 4 mg $S \cdot g^{-1}$ dry weight. The N:S ratio in leaves is considered less useful because it has a straight-line correlation with seed yield, making it impossible to determine a critical value for it [8, 13].

The N:S ratio is, however, the best indicator for assessing sulphur deficiency in hay. The critical value of this ratio, according to Richards (cited in [13]) is taken to be 20:1.

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SIARKA JAKO PIERWIASTEK NIEDOBOROWY W ROLNICTWIE – ROLA W PLONOWANIU I WPŁYW NA JAKOŚĆ SUROWCÓW ROŚLINNYCH

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Abstrakt: Siarka odgrywa specyficzną role w metabolizmie roślin. Bierze udział w syntezie białek, metabolizmie cukrów, wpływa na ilość i jakość tłuszczu w nasionach, decyduje o jakości mąki pszennej, wartości paszowej siana oraz walorach smakowo-zapachowych cebuli i czosnku. Funkcje, jakie pełni ten pierwiastek w życiu roślin, pozwalają zaliczyć go obok azotu, fosforu i potasu do grupy składników pokarmowych decydujących o ilości oraz jakości plonów roślin uprawnych. Rola siarki w żywieniu roślin zyskała na znaczeniu zwłaszcza w ciągu ostatnich kilku lat, kiedy to w większości krajów europejskich, w tym również w Polsce stwierdzono deficyt tego składnika w produkcji roślinnej. Związane to było przede wszystkim ze spadkiem emisji związków siarki do atmosfery oraz zmniejszeniem ilości tego składnika wprowadzanego do gleby z nawozami mineralnymi i naturalnymi. Funkcje jakie pełni ten pierwiastek oraz pogłębiający się deficyt tego składnika w środowisku wzrostu roślin wskazują, że siarka obok innych składników pokarmowych powinna być uwzględniana przy ustalaniu potrzeb nawozowych roślin uprawnych.

Słowa kluczowe: źródła siarki, siarka w roślinie, wielkość plonu, jakość plonu, siarka jako składnik deficytowy