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Review Article

PLANT PRODUCTION

Nitrate Accumulation in Plants and Hazards to Man and Livestock Health: A Review

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Abstract. This review presents information on nitrate accumulation in plant tissues, feasibility and effectiveness of decreasing its concentration through various manipulations and management practices of the solution nitrogen supply. It also focuses on the genotypic variations and relationships to plant nitrate reduction and assimilation capacity and hazards to human and animal health.

Introduction

Much recent interest and investigations have focused on high nitrate (NO_3^-) levels in the environment, in drinking water, and in food. In particular, fresh vegetables have been commonly cited as a major source of dietary intake of high concentrations of NO_3^- in humans [1]. High amounts of NO_3^- in edible plant parts may adversely affect both human and animal health due to the reduction of NO_3^- to nitrite (NO_2^-), which is a toxicant and a precursor of other harmful, and possibly lethal, compounds [2, 3].

Nitrate accumulation in plant tissues is largely controlled by three principal physiological processes; these are: NO_3^- uptake, assimilation, and translocation/partitioning [4]. Genotypic variation in NO_3^- accumulation potential in plants may be related to differences in one, several, or all of these processes. However, apart from genetic and physiological factors, NO_3^- accumulation in plants is also influenced to a great extent by environmental factors including, NO_3^- supply, light intensity, temperature, water and oxidation conditions in the soil [5, 6].

The common perception is that increasing the level of N nutrition increases the NO_3^- concentration in vegetables [7], although sometimes this may not be the case [8]. In addition, most leafy salad vegetables, such as lettuce, tend to be liberally fertilized with N to premote dark green colour, succulence and high yields. This concern is particularly acute in hydroponic culture where the need to supply and maintain adequate total amounts of mineral nutrients in conveniently small volumes of nutrient solutions has led to the use of high initial concentrations of many ions especially NO_3^- [4].

Much emphasis has been placed on breeding certain vegetable genotypes with low levels of tissue NO_3^- but results have been inconsistent. NO_3^- accumulation in plants may not be an easy heritable trait [9]. In addition, genotypic differences in tissue NO_3^- accumulation are likely to be influenced by interactions between various N supply with different N-forms and different factors and physiological processes of NO_3^- metabolism [10].

The present survey was made in an effort to characterize the extent and availability of data for NO_3^- accumulation in plants, the factors influencing it's occurrence and hazards to man and livestock health.

Hazards of nitrate to human and animal health

The major sources of nitrates in the human diet are vegetables, water and nitrates added to preservatives in prepared food products. Both NO_3^- (after transformation to NO_2^-) and NO_2^- in high concentrations or under special circumstances can be toxic and cause illness or death to humans. However, in actuality, it is the NO_2^- formed from the reduction of NO_3^- or present as a food additive causes the primary health hazard. The lethal NO_3^- dose for adults varies widely and is reported to range between 15 and 70 mg $NO_3^- kg^{-1}$ of body weight, while the lethal NO_2^- dose for adults is reported to be around 20 mg $NO_2^- kg^{-1}$ of body weight [2, 11]. Before ingestion, the reduction of NO_3^- to NO_2^- may occur through the action of microorganisms present in water, plants, or food during storage [3, 4], or by bacterial contamination of sterile food in opened containers [1, 12]. Natural plant enzymes may also contribute to some NO_2^- accumulation in stored foods. After ingestion, NO_3^- may be reduced to NO_2^- by nitrate-reducing bacteria present in the gastrointestinal tract.

Methemoglobinemia

Toxicity due to NO_3^- or NO_2^- can be either acute or chronic. Acute toxicity is expressed when NO_2^-, in large quantities, enters the blood stream and oxidizes the ferrous iron (Fe^{2+}) of hemoglobin to the ferric form (Fe^{3+}) producing methemoglobin, which can not transport oxygen (methemoglobinemia). It has been reported that unless immediate relief is provided, a proportion of methemoglobin that reaches to approximately 70% or more of the total hemoglobin may be fatal [2]. However, generally, methemoglobinemia cases are restricted to infants under 3 months of age and adults who are anemic and who genetically have high methemoglobin levels in their blood. It has been mentioned that in UK only 10 cases of methemoglobinemia (including 1 death) have been reported since the disease was first described [13].

Nitrates and cancer

Chronic effects caused by NO_3^- or NO_2^- toxicity are usually associated with nitrosamines, which are carcinogenic and mutagenic compounds [3]. The presence of NO_2^- and secondary amines may lead to the formation of nitrosamines. The fact that NO_2^- can interact with secondary amines to form nitrosamines is of particular concern because secondary amines are potentially present in a variety of sources including food, tobacco smoke, and numerous flavorings [14]. However, there is experimental evidence suggesting that ingestion of nitrates does not lead to formation of nitrosamines *in vivo* [15]. In addition, research has shown that high concentrations of NO_3^- in plant food can decrease the level of ascorbic acid, a known inhibitor of the formation of carcinogenic compounds that contain nitrite [16]. It has been estimated that over 80% of the total NO_3^- intake in humans originates from vegetables [17]. Although the risks have not been fully evaluated, several countries in Europe have established maximum permissible levels for nitrate concentration in vegetable food crops, and other countries are considering the establishment of similar standards. The Dutch government, for example, has set maximum permissible NO_3^- levels for lettuce. For example, for winter- grown lettuce the value is at 4500 mg NO_3^- kg^{-1} fresh weight and 3500 mg NO_3^- kg^{-1} fresh weight for summer-grown lettuce [5, 8]. As a result of increasing pollution of ground water sources adjacent to agricultural activities, the World Health Organization has set a limit of 10 mg NO_3^- -N L^{-1} in domestic water supplies [18-20]. Over 30 years ago, the U.S. Public Health Service established a similar standard for NO_3^- levels of 10 mg NO_3^- -N L^{-1} in drinking water [12].

Hazards to livestock

The principal hazard to livestock is due to the accumulation of NO_3^- by certain plants when they grow on soils containing an excess of the nitrogen. Wild plants such as *Panicum capillare*, *Cleome serrulata*, *Astragalus hamosus*, and many species in the genera Euphorbia, Heliotropium, and Tribulus may contain dangerous amounts of NO_3^- [21]. Nitrate and NO_2^- poisoning in ruminants has also followed heavy applications of sewage sludge in conjunction with a high level of nitrification in the absence of leaching under drought conditions and ingestion of sorghum hay and grass cubes made from a heavily fertilized pasture [1]. The clinical signs associated with the resultant anoxia appear when about 20% of the circulatory hemoglobin has been converted by NO_2^- to methemoglobin and death occurs at about 80% methemoglobin formation imparting a chocolate-brown discoloration to the blood with intrauterine death of the fetus and/or abortion, irritant effects on the gastrointestinal tract and vasodilation of the peripheral blood vessels resulting in stagnant anoxia [21, 22].

Nitrate accumulation in vegetables and wild plants

Nitrate accumulation in plants is a natural occurrence resulting from NO_3^- uptake in excess. The tendency or phenomenon, for NO_3^- to accumulate in certain plant species in the families Amaranthaceae, Chenopodiaceae, Cucurbitaceae, Cruciferae, Graminae, and Solanaceae was described [22]. Plants in the Asteraceae were then added to species of high NO_3^- accumulators [6]. For plants in the Chenopodiaceae and Cruciferae families, it is generally believed that the high levels of tissue NO_3^- may be an evolutionary feature related to the ability of these plants to tolerate high salt conditions, or a consequence of an inefficient NO_3^- -reducing system or a result of accumulation of NO_3^- for assimilation purposes after reduction to NH_4^+ [21, 22].

It is generally recognized, in plant nutrition, that vegetables and forage crops tend to accumulate NO_3^- to a greater degree than most other cultivated crops [23-25]. However, any classification of plants as high or low NO_3^- accumulators should be viewed with circumspect and in context from both consumer and cultural perspectives, since the plant part sampled and the rate of fertilization greatly affect NO_3^- accumulation [8]. It has been found that edible portions of fruits and nuts do not accumulate NO_3^- to any significant degree. On the other hand, vegetables routinely receive high rates of N fertilizer could accumulate NO_3^-. Some plant parts, such as pepper fruits or kernels in corn, accumulate very low levels of NO_3^- regardless of the rate of N fertilization, while the levels of NO_3^- in the leaves of these crops may be quite high. Among vegetable crops, lettuce and cucumber, along with spinach, is routinely ranked as one of the highest accumulators of NO_3^- [6, 8, 23, 24]. NO_3^- -N concentrations up to approximately 0.6% (dry weight basis) were reported in wrapper leaves of heavily fertilized commercial field-grown 'Boston' lettuce in California [8]. This figure compares favorably with leaf $NO3^-$ -N levels of 1.06% (dry weight basis) reported in field-grown leaf lettuce in Missouri [23]. It has been pointed out that lettuce has the capacity to accumulate NO_3^- to concentrations that far exceed what is required for maximum growth [24]. The same authors cited that excess $NO3^-$ accumulation in leaf lettuce amounted to 103% of the maximum growth requirement. Such high NO_3^- accumulation in excess of plant growth requirements in lettuce has been attributed to a reserve role of NO_3^- as an osmoticum when photosynthesis is too low to supply adequate levels of sugars and organic acids to build amino acids [26].

Differences between lettuce growth types (crisphead, butterhead, romaine, leaf) and their respective genotypes and cultivars in their capacity to accumulate NO_3^- are well documented [10, 27, 28]. It has been shown that crisphead cultivars contain higher NO_3^- than other lettuce types [24]. In two independent but related research experiments, different cultivars of similar lettuce types growing under comparable conditions were found to have variations up to 3-fold in their leaf NO_3^- concentrations[10, 28]. Although large differences in tissue NO_3^- content among different lettuce types were reported, differences among cultivars of the same growth type were small and inconsistent [8].

As indicated above, NO_3^- tends not to be uniformly distributed throughout the plant, but rather tends to accumulate in certain plant parts. In general, NO_3^- concentrations are lowest in floral parts, with increasing concentrations found in fruit, grain, leaves, roots, and petioles or stems, in that order. In particular, the petioles and midribs have been identified as major accumulation sites of NO_3^- in lettuce [29]. As such, it seems that the proportion of vascular and foliar tissue can greatly affect NO_3^- accumulation in lettuce. Within a plant part, NO_3^- concentrations are usually higher in older tissues. In a recent study, NO_3^- concentrations were highest in the outer, older leaves in lettuce, and lowest in young, internal leaves [30]. The NO_3^- content in outer leaves was found to be two- to four-times higher than that measured in the leaves at the center of the plant young leaves[31; 32] and was attributed to higher rates of transpiration and translocation of NO_3^- in these tissues of lettuce and maize [33].

Genotypic and species differences in NO_3^- accumulation may be related to differences in various physiological processes of N metabolism in plants, including uptake, reduction/assimilation, and translocation /partitioning [4; 34]. Cultivars can vary in efficiency of N assimilation, and accumulation of NO_3^- may be associated with a reduced capacity for NO_3^- reduction and a low NRA [35]. Inorganic nitrogen assimilation was responsible for differences in NO_3^- concentrations in spinach genotypes; savoy-leaf cultivars accumulated more NO_3^- than smooth-leaf cultivars because the latter possessed a higher NRA and dry matter content [36]. Lettuce genotypes that accumulated significantly different NO_3^- concentrations in their leaves exhibited similar NO_3^- reduction capacities, and subsequent genotypic variation in NO_3^- accumulation was attributed to factors other than reduction potential, inferring differences in NO_3^- uptake capacities as a possible factor[27]. It was reported that varietal differences in tissue NO_3^- content in corn was independent of genotypic differences in NRA levels, and that suggestions for differences in NO_3^- uptake capacity as a leading contributing factor were proposed [37; 38].

In addition, the various physiological processes of N metabolism affecting genotypic differences in NO_3^- accumulation, in turn, may be affected by environmental factors, such as N supply [39], photosynthetic photon flux [26; 30], and temperature [40]. How these various factors interact is still unclear, and in many cases results are contradictory. When fourteen cultivars of crisphead lettuce were screened for NO_3^- accumulation under various field conditions, differences in leaf $NO3^-$ concentrations as great as five-fold were observed [23]. However, while it was clear that the magnitude of the genotypic differences in NO_3^- accumulation depended on the environmental conditions, the relative ranking of high and low NO_3^- accumulators remained fairly consistent, indicating that genetic influences were of enough significance so as not to be masked by environmental effects.

Genotypes can also accumulate NO_3^- to different levels due to their differential translocation or partitioning characteristics. In many crops, there appears to be a very clear intrinsic, or hereditary, difference between species in the proportion of nitrate supply assimilated in roots and translocated to the shoots. Some plants such as species of Xanthium, Gossypium and Cucumis appear to lack root nitrate reductase, and therefore transport all their nitrogen to shoots as NO_3^- [41]. At the other extreme, some gymnosperms reduce nitrate mainly in their roots and transport very little to the shoot [42]. In many species, most of the nitrate absorbed by the roots is translocated in the xylem to the leaves, where it is either, assimilated or stored in the vacuoles; for example, barley [43], lettuce [27], maize [44], and Chrysanthemum [45].

Genotypic differences in photosynthetic capacities could lead to differences in the synthesis of organic acids and sugars, and thus to differential NO_3^- accumulation [27].

This hypothesis was based on evidence to the effect that NO_3^- under low light intensities could serve as an osmoticum to make up for the deficit in the osmotically active organic compounds when photosynthesis is reduced [26].

In general, NO_3^- accumulation in plants is in a dynamic state, a product of NO_3^- absorption, translocation, and assimilation. The reasons cultivars differ in NO_3^- accumulation may vary; one may have an especially high assimilatory capacity in the leaves, another may absorb less NO_3^-, one may reduce a large portion of absorbed material in the roots thus translocating less NO_3^- to shoots, another may have a lower ratio of petioles to blades, and so forth. All of these processes may, in turn, be affected by environmental variables. In addition, plant NO_3^- concentrations will vary with plant part and plant age.

In the last few years, considerable breeding work has been initiated in vegetables particularly in lettuce, with leaf NO_3^- concentrations as primary selection criteria. Using butterhead, crisphead, romaine, and leaf types, it has been shown that NO_3^- accumulation in lettuce is an heritable trait, with a few major genes responsible for genetic control of high or low NO_3^- accumulation [46]. The same authors have shown that high NO_3^- accumulation is controlled by recessive genes, and low NO_3^- accumulation controlled by complementary genes *A* and *B*; a single gene *C*; and a combination of *ABC* genes and that the involvement of few genes in the control of low NO_3^- accumulation should facilitate breeding for low NO_3^- accumulation.

It is well known that more than 1,000 lettuce accessions have been screened in several trials for NO_3^- accumulation and that extremely high NO_3^- content is found within the group of the wild *Lactuca* species and the lowest NO_3^- content is detected in genotypes that are not adapted to modern cropping practices [47]. These accessions can be used to breed for NO_3^- levels below those found in all cultivated lettuce types (butterhead, romaine, crisphead, and leaf). The low level of NO_3^- found in these accessions would be a valuable contribution to the efforts aimed at reducing the human NO_3^- consumption. The average reduction in select cultivars, the accession with the lowest NO_3^- levels, were about 50 % compared with modern lettuce cultivars [28].

Nitrogen supply and nitrate accumulation

Since nitrate in plants is derived primarily from nitrate added or formed in the medium, N supply is perhaps the most important nutritional and environmental factor influencing NO_3^- accumulation in vegetables [23]. The amount and source of N applied, and the time and method of N application will determine the effects of N fertilization practices on NO_3^- levels in vegetables.

A cardinal rule in N fertilization is that sufficient available N be present to meet crop growth requirements. When higher rates of N are provided storage as excess NO_3^-, and translocation within the plant when needed will take place. Any unused NO_3^- in the soil at the time the crop is harvested is usually of little value, and is itself subject to leaching. However, because of consumer quality and marketing demands, vegetables, unlike field and forage crops, usually require fertilization rates in excess of crop removal requirements [48]. It is known that due to stringent market demands for green leaves free of unsightly blemishes, fertilization rates in lettuce commonly exceed crop growth requirements and that lower N fertilizer rates may affect yield and crop sales at market [4; 48].

In most crops, as in lettuce, increasing the level of N addition increases the NO_3^- concentrations in vegetables, and that an increase in N supply beyond the plant's immediate need will generally cause a disproportionately larger increase in stored nitrate as compared to total N [8; 49]. Many vegetables including tomato plants can accumulate and tolerate very high levels of NO_3^- as a result of high N fertilizer rates; sometimes NO_3^- in excess of 18,000 μg NO_3^- N g^{-1} dry weight [50]. Therefore, unlike many other plant nutrients, which can be toxic at high levels, high concentrations of NO_3^- will generally lead to accumulations exceeding current demands for growth.

Only at very low NO_3^- concentrations in the tissue, growth is very often limited. It was reported that growth of lettuce was depressed at 2 mM NO_3^- due to N deficiency, and at 36 mM NO_3^- due to salt toxicity [51]. At N application levels of 18 and 36 mM NO_3^- there was no significant difference in leaf total N concentration, but the relative amount of NO_3^- increased almost 3-fold. It was shown that with sugar beets, fertilization with 560 kg ha^{-1} N as compared to no fertilization, increased NO_3^- accumulation 70-times in the petioles, 30-times in the blades, and 20-times in the roots[8]. Equally significant was the increase in NO_3^- -N as related to total N, with the proportion on NO_3^- -N increasing from 3.7% to 88.4% in the petioles, from 2.4% to 38.2% in the blades, and from 4.8% to 77.4% in the roots.

In general, tissue NO_3^- concentrations in plants are very responsive to N fertilizer practices, and subsequently provide a reliable indicator of plant N status. While total N in the plant results from accumulated N uptake, NO_3^- -N indicates the N status at a given sampling time. In the plant, NO_3^- serves as a reservoir of unassimilated N, and until it falls below a critical level, growth and yield are not affected. Depending on the plant N status, tissue NO_3^- concentrations will generally decline as N supply levels are depleted or removed, although plant growth may or may not necessarily be affected. Removal or decrease in N supply may result in a slow but consistent decline in relative growth rate, which is maintained until the tissue NO_3^- is almost depleted, whereupon growth falls rapidly. It was found that withdrawing all nitrogen from the nutrient solution about 7 to 10 days before harvest, reduced the nitrate concentration of lettuce significantly without any serious effect on crop yield [52]. It was reported that dry matter production in lettuce was restricted as soon as the external N supply was withheld, irrespective of the plant nitrate status [53]. It was also suggested that NO_3^- concentrations in excess of 0.1 mM g^{-1} are required in lettuce to avoid serious reductions in growth rate when N is in short supply.

The source of N fertilizer can have marked effects on NO_3^- accumulation in plants. It is well established that NO_3^- sources of N result in higher NO_3^- levels in vegetables than ammoniacal sources, and that using ammonium or a mixture of nitrate and ammonium as fertilizers can help to reduce nitrate accumulation in plants [23]. However, rapid conversion of NH_4^+ to NO_3^-, through the process of nitrification, substantially limits the effectiveness of using ammoniacal N as means of maintaining low NO_3^- levels in vegetables [54]. When nitrification inhibitors are used nitrification is not completely inhibited in lettuce [55], spinach [56], and radish [57]. In each of these studies, however, significant growth reductions, especially at high rates of N application, were observed relative to treatments in which the major proportion of N was supplied from NO_3^- source. It is known that when plants are grown on NO_3^- only nutrient medium will show chlorosis due to an increase in PH. The use of NH_4^+, especially at high N rates, whether alone or in combination with nitrification inhibitors, is not a standard production practice in many commercial vegetables due to deleterious effects on plant growth, as well as poor plant quality, with ammoniacal sources of N; there are, however, large differences in the tolerance to NH_4^+ among species [58].

Although most crop species can utilize either NO_3^- or NH_4^+, several researchers working with lettuce, utilizing mixtures of these ions, have shown reduced NO_3^- concentrations in plants by varying the NO_3^- :NH_4^+ ratio of the N supply. Using a recirculating nutrient solution system, NO_3^- accumulation by lettuce was reduced by about 18% in winter lettuce and 8% in summer lettuce when 20% of the total N (present as 10.0 mM NO_3^-) was replaced by NH_4^+, with no reduction in growth [40]. A further increase in the proportion of NH_4^+ in the nutrient solution to 50% and 80% a few weeks before harvest decreased leaf NO_3^- concentration even more, while fresh weight was unaffected or decreased slightly. However, temporarily omitting all N in the late part of the growing season resulted in the lowest NO_3^- concentrations, but also sharply reduced fresh weight. It has been found that partial (25 NO_3^-:75 NH_4^+) or complete substitution of ammonium for nitrate in the solution reduces both the NO_3^- concentration in lettuce as well as growth [59].

Unfortunately, in each of the above studies, the precise manner in which mixed-N supply reduced NO_3^- accumulation in lettuce was not addressed. However, information about the mechanisms for these results can be gleaned from the results of other researchers. Evidence for both direct and indirect mechanisms for NH_4^+ -induced inhibition of NO_3^- uptake have been proposed. As a direct action, NH_4^+ can interact with NO_3^- transporters at either the external or internal surface of the plasmalemma [60] or alter membrane permeability in wheat (*Triticum aestivum*) due to high acidity resulting from NH_4^+ absorption [61].

Some researchers have suggested that NH_4^+, or products of its assimilation (e.g., amino acids), can adversely affect NO_3^- uptake indirectly by inhibiting the reduction of NO_3^- possibly inhibiting the enzyme nitrate reductase [62]. In wheat, the inhibition from NH_4^+ was greater for NO_3^- uptake than for NO_3^- reduction [63], while in maize seedlings, NO_3^- reduction was inhibited approximately 48% and uptake by 20% [64]. Despite these differences, NO_3^- uptake and reduction may be closely related. While uptake regulates the availability of substrate for reduction, the process of reduction generates OH^- ions, which contribute to the driving, force for NO_3^- uptake [59, 65]. In contrast, other studies investigating a range of species have shown an inhibition of NO_3^- absorption without a decrease in NO_3^- reduction [66].

The method and the time of N application can directly impact the effects of N supply on NO_3^- accumulation in vegetables. Fertilizer N broadcast before planting, resulted in NO_3^- concentrations that were double those of equivalent sidedressed applications [54]. In general, the longer that a plant is in contact with a NO_3^- rich medium the greater will be its tendency to accumulate nitrate. However, NO_3^- concentrations will decline rapidly as crops reach maturity, particularly when fertilized at planting, and the N supply is being depleted [50]. Materials that mineralize slowly, such as dry cow manure, lead to lesser NO_3^- accumulation in vegetables than materials that mineralize more rapidly [58].

Importance of solution flow rate on nutrient uptake

Mineral nutrition of plants, including ion uptake and absorption, depends on both the concentration of nutrients in the root environment, and their rate of movement, or replenishment, at the root surface. With low but constantly maintained concentrations of ions in solution, plant roots can be extremely efficient in nutrient uptake [67]. It was reported that a constant supply of 1 mM NO_3^- was sufficient to meet the N requirements for optimum growth rate in corn, sorghum, and brome grass [68]. Using a very precise flowing culture technique, it was shown that at a constant NO_3^- supply of 1.4 μM and a flow rate of 729 ml min^{-1} /pot, ryegrass was able to maintain rates of NO_3^- uptake of about 85% of maximum, clearly demonstrating that vigorous growth can be obtained in quite dilute flowing culture solutions [69]. There is general recognition in plant nutrition that as the rate of flow of nutrients across the root surface (flux) increases, the concentration of nutrients required for growth decreases [70].

For nutrients, such as ammonium, potassium and phosphate, which are taken up rapidly by plant roots, and which are generally present in the soil solution in low concentrations, transport to plant roots is primarily by diffusion [71]. For nutrients such as calcium, which are present in the soil solution in high concentrations, and whose uptake is highest when transpiration rates are high, movement to the root surface is mainly by mass flow. In the case of NO_3^-, transport to the root surface can occur by either diffusion or mass flow. Investigations have shown that under field conditions mass flow is the major process in transporting NO_3^- to the root surface at the beginning of the growth period, but in the later growth stages, when the NO_3^- concentration in the soil solution is low diffusion becomes the dominant process of NO_3^- transport [72]. Regardless of the transport mechanism, however, if the rate of NO_3^- uptake by the plant is higher than the rate of nutrient transport to the root, depletion zones will occur around roots.

In recent years, continuous flow techniques have gained in popularity and use for both commercial production and plant nutrition research purposes [73]. Continuously flowing solution culture provides the most practical means for precise control of root environment parameters, and allows plants to be grown for extended periods of time with very close control of root temperature, PH, and nutrient ion concentrations in dilute solutions, comparable in composition with soil solutions[74]. However, when using flowing culture techniques to characterize nutrient uptake and utilization, it is important that solution flow rates are high enough to ensure that minimal depletion of the solution occurs as the solution passes through the root microenvironment. Higher flow rates are required to restrict depletion to an acceptable value in studies of element efficiency, in contrast to studies of element toxicity [75]. At lower flow rates, solution depletion resulted in substantial reductions in growth and nitrogen uptake [76]. On the other hand, flow rates as low as a few ml per pot min^{-1} may be perfectly satisfactory for experiments conducted at high and non-limiting nutrient ion concentrations. In addition, problems of oxygen depletion had been observed with low flow rates in 15 cm wide and 12 meter-long gullies [77].

Nitrate accumulation in hyroponically-grown lettuce cultivars and relationship to nitrogen supply have been recently investigated [4].

Investigations of NO_3^- concentrations in vegetables and wild plants in Central Saudi Arabia and the factors influencing its occurrence as well as the effects on domestic animals, chickens and rats are in progress.

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تراكم النترات في النباتات وأثره الضار على صحة الإنسان والحيوان

(مقالة استعراضية)

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(قدم للنشر في ١٣/٦/١٤١٩هـ؛ وقبل للنشر في ٢٣/٢/١٤٢٠هـ)

ملخص البحث: يحتوي هذا البحث على معلومات عن تراكم النترات (NO_3^-) في أنسجة النباتات واستعمال طرق عملية مؤثرة بغية تقليل تركيزها في أجزاء النباتات وذلك بالتحكم في التسميد الأزوتي وإنتاج أصناف نباتية ذات طبيعة وراثية متميزة في اختزال النترات لتفادي الأذى على صحة الإنسان والحيوان