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Mineral nutrition of tomato

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Summary

Tomato is one of the popular vegetable consumed by most people and enriched in nutrients and taste. The amount and type of nutrients supplied to tomato can influence not only its yield but also its nutrient content, taste, and post-harvest storage quality. While some nutrients, such as N, P, K, Ca, Mg, and S, are needed in large amounts by tomato for normal growth and reproduction, others, such as Fe, Cu, Zn, Mn, B, Mo, and Cl, are needed in small amounts. As a result, tomatoes are regularly fertilized with N, P, and K and occasionally with Ca and Mg from liming to adjust soil pH. Other nutrients are not normally applied unless deficiency in plants occurs. For tomatoes grown in the greenhouse, the growth media other than soil is fortified with all nutrients. Excess level of nutrients that are more than needed by plants can reduce tomato yield, increase fertilizer-use inefficiency and cost of fertilization, and degrade environmental quality. Therefore, periodic analysis of soil and plant samples should be conducted to determine the proper rate of fertilization that will reduce the cost of fertilization and environmental degradation without significantly altering tomato yield.

Key words: Mineral nutrients, tomato, nutrient uptake, fertilization, environmental quality.

Introduction

Tomato is one of the popular and most consumed vegetable in the world. It is tasty and easily digestible and its bright color stimulates appetite. As a result, it is grown in the backyard of most people's home. It is consumed as salad with other leafy vegetables, in sandwiches, and as stewed, fried, and baked singly or in combination with other vegetables. It is an essential ingredient in pizza, pasta, hamburger, hot dogs, and other foods. It is also rich in nutrients and calories. It is a good source of Fe and vitamin A, B, and C (Table 1). A 230 g of tomato consumption can supply about 60% of the recommended daily allowance of vitamin C in adults and 85% in children [38]. Similarly, consumption of 100 mL of tomato juice can supply 20% of the recommended daily allowance of vitamin A. Consumption of tomato and its products can significantly reduce the risk of developing of colon, rectal, and stomach cancer. Recent studies suggest that tomatoes contain the antioxidant lycopene, the most common form of carotenoid, which markedly reduces the risk of prostate cancer [14]. Because the mineral composition of tomato depends on the amount and type of nutrients taken from the growth medium, such as soil, it is necessary that adequate amount of nutrients should be available for the production and nutrient content of tomatoes. While inadequate amount of nutrient availability can show deficiency symptom and influence the yield and quality of tomato, higher level of nutrients, such as N, can also reduce tomato yield by producing excess biomass at the cost of fruits and lodging of entire plant in the ground, which makes harvest of fruits more difficult. Because tomatoes are unable to recover 100% of applied N [30, 37], the residual N in the soil left after harvest can leach from the soil profile and contaminate groundwater, thereby degrading water quality and wasting the amount and cost of fertilizer applied. Similarly, excess availability of some nutrients, such as B and Mn, can cause toxic effect. Therefore, rate and type of nutrients applied in the form of fertilizers should be adjusted after analyzing the nutrient contents of soil and plant samples.

Mineral Nutrients

Tomato requires at least twelve nutrients, also called "essential elements", for normal growth and reproduction. These are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and molybdenum (Mo). The function of these nutrients and their concentrations in different parts of tomato are shown in Tables 2 and 3. Without these nutrients, tomato can not grow properly or bear fruits. For example, N is an essential component of many compounds, including proteins, amino acids, and enzymes responsible for biochemical changes in tomato growth [43]. While some nutrients, such as N, P, K, Ca, Mg, and S (also called macronutrients), are needed in large amounts for optimum production because the concentration of these nutrients are higher than other nutrients in tomato (Tables 2 and 3), others, such as B, Fe, Mn, Cu, Zn, and Mo (also called micronutrients), are needed in small amounts. Because soil can not supply adequate amounts of N, P, and K for optimum growth and production of tomato, these nutrients are added as amendments in the form of manures and fertilizers to the soil. Nutrients, such as Ca and Mg, are applied when liming is done in acidic soils. Some soils contain abundant amount of Ca and Mg. Sulfur is usually supplied by N, P, and K fertilizers because many of these fertilizers contain S compounds. In contrast, micronutrients are usually supplied in adequate amounts by the soil unless deficiency in plant occurs. In the greenhouse tomato production where soil is not generally used for growing tomatoes, the growth medium, however, needs to be fortified with all of these nutrients. The method and timing of nutrient application from fertilization can also influence the growth and production of tomato and fertilizer-use efficiency. While N and K fertilizers can be applied either by broadcasting or banded along the rows, P fertilizer should be banded to increase its availability because P is relatively immobile compared with other nutrients. Because N is soluble in water and residual N can be leached from the soil profile to the groundwater, N fertilizer is usually divided into two to three split doses and each dose is applied at 3 to 6 weeks intervals from the date of transplanting. This maximizes the synchrony between N applied from the fertilizer and N need of the plant during active growth. Micronutrient fertilizers are usually applied through foliar spray.

Nitrogen: Nitrogen is the most limiting nutrient for tomato growth and is required in large amount for optimum production because tomato removes large amount of N from the soil (Table 4). Nitrogen deficiency in the soil can result in stunted spindly growth and yellowing of leaves at the base of tomato plant [23]. Younger leaves remain small and pale green, and in severe cases, older leaves become yellow and die prematurely. It can decrease the production of number of fruits, fruit size, storage quality, color, and taste of tomato. Nitrogen is a constituent of protein and amino acids, without which vital functions in the growth and reproduction of plants would not be possible [43]. While N deficiency in tomato can result from N removal by plant from the soil after the harvest of aboveground plant biomass, absence of soil amendments, such as manures and fertilizers, and N loss from erosion, runoff, and leaching, addition of plant materials with high C:N ratio can also accelerate the deficiency due to immobilization of N in the soil. Adequate amount of N should be available in the soil not only for optimum growth and production of tomato but also to produce sufficient foliage to protect the fruit from the exposure of hot sun [8]. High N level in the soil, on the other hand, can promote excessive vegetative growth which can delay the setting and maturity of tomato fruits, thereby reducing tomato production [12, 44]. It can also turn younger leaves into smaller sizes and darker color, often puckered or curled [23]. Root tips may turn brown and die back, and in severe cases, most of the root system may be killed. As N applied from manures and fertilizers to the soil is readily converted into NO_3 for plant uptake, high rate of N fertilization can result in large amount of residual NO_3 build up in the soil after crop harvest. Because NO_3 is soluble in water, high concentration of residual NO_3 can increase the potential for N leaching from the soil and contaminate groundwater. The problem can be severe in sandy soils which have higher water infiltration and lower NO_3 retaining capacity compared with clay soils. The type of N fertilizer applied can also influence tomato production because NH_4-N can be toxic to tomato growth compared with NO_3-N [16, 19]. To obtain a best management practice that can sustain tomato yield, reduce the amount of N fertilization and N leaching, and improve soil quality and productivity, Sainju et al. [30, 31, 32] conducted experiments on the effects of tillage, cover crops, and N fertilization rates on tomato fruit yield, biomass production, and soil nitrogen (Tables 5 and 6, Fig. 1). While chisel plowing (minimum tillage) was as good as moldboard plowing (conventional tillage) in producing tomato yield and N uptake, yield and N uptake were similar between 90 and 180 kg $N \cdot ha^{-1}$, although both N rates produced higher yield and N uptake than without fertilization (Tables 5 and 6). Similarly, yield and N uptake were similar between legume cover crops (hairy vetch and crimson clover) and N rates (Table 6). In contrast, residual soil NO_3 accumulation after tomato harvest in the autumn (September 1997) and movement within the soil profile from autumn to the following spring (March 1998) increased with increasing N fertilization rate (Fig.1). The results suggests that a management practice containing minimum tillage, legume cover crops, and reduced rate of N fertilization can be used to sustain tomato yield and N uptake and reduce soil erosion, rate of N fertilization, and potential for N leaching.

Phosphorus: Phosphorus helps to initiate root growth of tomato and therefore aids in early establishment of the plant immediately after transplanting or seeding. Starter solution containing high concentration of P is normally applied to tomato plants within few days after transplanting for early root development and establishment in the soil. The vigorous root growth stimulated by P helps in better utilization of water and other nutrients in the soil and promotes a sturdy growth of stem and healthy foliage [8, 24]. Phosphorus is a component of nucleic acid. It helps in the production of large number of blossoms in the early growth of tomatoes and early setting of fruits and seeds [45]. As a result, it increases the number and production of tomato fruits, with increased total soluble solids and acidity contents [3]. It also improves the color of skin and pulp, taste, hardiness, and vitamin C content [36]. Deficiency in P results in stunted growth of tomatoes with thin stems and dark green color on the upper surface of leaves containing purpling veins [23]. Older leaves show premature senescence with yellow and purple tints. Unlike N, P is strongly absorbed by soils. As a result, most soils contain abundant amount of P, as it hardly leaches out of the soil profile. Because tomatoes take up relatively smaller amount of P than the amounts of N and K, the concentration of P in tomato is also smaller (Tables 2, 3 and 4). As a result, smaller rate of P from manures and fertilizers is added to soil (Table 3). Because of its relatively immobile nature compared with other nutrients, band application of P along rows is desirable for its maximum availability to the plants. Water soluble P fertilizers, such as nitro-phosphate or triple super phosphate, are desirable to tomato for its rapid availability [41]. Compared with most other nutrients, excess level of P in the soil is less harmful to tomato. However, it can reduce the availability of some micronutrients, such as Fe, Zn, Mn, and Cu, by decreasing their solubility in the soil and translocation within the plant [1, 23]. The problem can be severe at high soil pH or in calcareous soil [2, 21].

Potassium: As with N, K is absorbed by tomato in large amount (Tables 3 and 4) because K concentration in tomato is higher than the concentration of other nutrients (Tables 2, and 3). Potassium helps in vigorous growth of tomato and stimulates in early flowering and setting of fruits, thereby increasing the number and production of tomatoes per plant [39]. Potassium nutrition can affect the quality of tomato fruit. Winsor [43] observed that the percentage of unevenly ripened tomatoes and irregularly shaped and hollow fruits decreased with increased K rate (Table 7). In contrast, titratable acidity of tomato juice increased with increased K rate. Symptoms, such as 'blotchy ripening', 'waxy patch', 'uneven pigmentation', 'vascular browning', 'white wall', 'gray-wall', and 'coud', in tomato fruits also decreased but flavor increased with increased rate of K fertilization [11, 43]. Potassium is needed in stomatal movement for water regulation in the plant. It helps to activate enzymes and is required for carbohydrate metabolism and translocation, nitrogen metabolism and protein synthesis, and regulation of cell sap concentration [8]. It also increases the concentrations of citric and malic acids, total solids, sugars, and carotene in tomato fruits, thereby improving its storage quality [41]. Potassium deficiency results in brown marginal scorching with interveinal chlorosis and yellowing in tomato leaves [23] and shortened internodes [41]. Symptoms appear first on older leaves and start to spread throughout the plant as it matures. Fruits ripe unevenly. The deficiency can also result in lower content of lycopene, a constituent that can prevent prostate cancer in humans [8]. The deficiency can appear rapidly in tomatoes grown in peat and peat-sand composts that are low in K content due to flooding or application of heavy irrigation. Excess K level in the soil can have hardly any direct effect on tomatoes but it can reduce the availability of Mg in the soil. Needham [23] suggested that a 2:1 ratio of K and Mg contents should be maintained in the soil to reduce Mg deficiency while applying K. Like N, K is soluble in water and can be leached out of the soil profile into the groundwater. Although health hazard of high concentration of K in drinking water is not known, it is important to reduce K leaching in the groundwater to reduce the cost of fertilization and improve water quality. As a result, periodic soil or plant analysis needs to be conducted before applying K fertilizer to tomato so that adequate amount of K is available for optimum production and leaching can be reduced.

Calcium: Besides N, P, and K, Ca is also needed by tomato in large amount because of its higher concentration in the plant components (Tables 2 and 3). Fortunately, most soils contain adequate amount of Ca for tomato growth. Calcium deficiency occurs when soil pH is <4.5. In such condition, lime is applied to raise the soil pH. The normal range of soil pH for optimum tomato growth is from 5.5 to 7.0. Excessive liming, however, should be avoided, as it can result in the deficiency of micronutrients, such as Fe and Mn. High concentration of free $CaCO_3$ in the soil can decrease P availability in the soil [1]. Soils are normally limed every 3 to 5 yr to adjust pH. Calcium deficiency can cause a well known disorder, called "blossom-end rot", in tomato fruits. The disorder is caused by the lack of movement and distribution of Ca within the plant, although soil is not deficient in Ca. Although leaves may contain abundant amount of Ca, fruits may not. Affected fruits start to rot at the bottom which spread upwards. Wiersum [42] observed that the disorder occurred below a Ca concentration of 800 $mg \cdot kg^{-1}$ in the fruits. Dry soil and high K content in the soil accelerate the disorder [23]. High concentration of soluble salts in the soil or fluctuating water content can also increase the disorder. The disorder can be reduced by spraying the foliage with Ca solution, by flooding the soil if salt content is high, or by irrigating more frequently if the rooting volume is restricted. Calcium deficiency can also turn young leaves to pale green or yellow and finally to brown. Leaflets remain small and curled and the growing points start to die.

Magnesium: Magnesium is a component of chlorophyll, pectin, organic acids, and coferments. Tomato fruit production is significantly increased by applying Mg fertilizer (Table 8). Magnesium deficiency is common in tomatoes grown in the greenhouse. Symptoms appear as interveinal chlorosis in leaves at the base of the plant which extend upwards. Older leaves become yellow or orange and brown necrotic areas develop between the veins before the leaves drop. Deficiency may not affect fruit production unless the problem is severe. The deficiency can be observed in sandy soils, soils high in K level where K:Mg ratio is >4.0, and in soils with poor structure or drainage [23]. Magnesium deficiency can be reduced by spraying $MgSO_4$ (Epsom salt) at 2.6 $g \cdot L^{-1}$ in the foliage several times during tomato growth. Applying dolomitic limestone to raise soil pH can supply both Ca and Mg requirement of tomato.

Sulfur: Sulfur is a constituent of protein and amino acid. Deficiency of S in the field is rare because it is usually applied in combination with N, P, and K fertilizers. Tomatoes can also absorb S as SO_2 from the atmosphere, but exposure to >0.5 $mg \cdot L^{-1}$ of SO_2 can cause water-soaked spots on the middle and lower leaves, which become white, dry, and papery. Sunken white spots may also appear on tomato fruits. In contrast, deficiency of S can cause interveinal chlorosis on the leaves and purpling of veins and petioles, which can lead to purple spotting and necrotic patches between the veins in severe condition. The deficiency can appear in soilless medium or water culture that is low in S content.

Boron: Boron plays a significant role in the insemination and reproductive growth of tomato. It can influence on the production of tomato flowers and fruits. Boron deficiency is one of the widely reported nutritional disorder in commercial tomato production. The deficiency often occurs in soilless compost and calcareous sandy soils. The disorder occurs as turning of green leaflets to yellow that become brittle with brown pigmentation in the vein. In severe cases, leaf chlorosis and distortion, production of later distortion, production of later points can occur [23]. The deficiency can also reduce root growth and cause swollen hypocotyls and cotyledons, irregular leaf expansion, shortened internodes, and abnormalities in cellular structure [41]. The deficiency is accelerated by increase in soil pH and dryness around the root zone. Gallagher [7] observed that B deficiency occurs when the level in the tomato tissue falls below 19 $mg \cdot kg^{-1}$. The deficiency can be reduced by spraying borax solution in the foliage at 0.5 $mg \cdot L^{-1}$ or applying borax in the soil at 22 $kg \cdot ha^{-1}$. Kocevski et al. [13] observed that application of B fertilizer significantly increased yield of greenhouse tomato (Table 8). Excess level of B, however, can cause brown marginal scorching and curling of older leaves [23]. The necrosis becomes dry and papery and interveinal necrotic spots appear. Ash and waste products used as soil conditioners can contain high levels of B and can induce B toxicity to tomatoes. The toxicity can be reduced by flooding or liming the soil.

Iron: Iron is a constituent of many enzymes in the nutritional metabolism of tomato (Table 2). Iron deficiency occurs mostly in soils with high pH, in calcareous soils, and in soilless medium. The deficiency appears as pale yellow interveinal chlorosis on younger leaves near the base of the plant. In severe case, white chlorosis develops on the entire surface of the leaves, with the veins remaining green. The leaves remain small and plant growth stunted. The disorder is accentuated by poor soil structure or drainage, often in heavy-textured alkaline soils. It can also occur on acid peat soils. Excess level of P in the soil can decrease the solubility of Fe and its translocation in tomato, thereby increasing its deficiency. The disorder is hard to be diagnosed by plant or soil analysis. As a result, visual symptom and response to the application of Fe in tomato growth is the best way to identify the disorder. The disorder can be reduced by improving soil structure and drainage and reducing soil pH, such as by enhancing the soil organic matter content with application of compost or manure. The deficiency can also be reduced by spraying Fe chelate (Fe-EDTA) at 37 $mg \cdot L^{-1}$ in tomato foliage every 2 weeks [23].

Manganese: As with Fe, Mn deficiency is induced by high soil pH. Although less common in most field soils, Mn deficiency can appear in tomato plants grown in sandy soils, organic soils, and peats due to overliming. The symptom appears as pale green or yellowish interveinal chlorosis in the middle and younger leaves, leading to brown necrotic spots in the center of the pale area. Although the symptom is less severe than that caused by Fe deficiency, Mn deficiency can be detected by plant analysis. The deficiency can be reduced by spraying $MnSO_4$ at 6 kg ha^{-1} several times during tomato growth. Sterilization of soil with steam to control pathogens in the greenhouse can increase Mn availability and toxicity to tomato. This is because sterilization provides ideal environment for microorganisms to reduce organically bound Mn and Mn^{3+} into Mn^{2+} at high temperature [43]. Wet and compacted soils are more likely to show Mn toxicity in such condition. The symptom appears as brown necrotic spots between veins on the middle leaves of tomato, which extend to midribs and main lateral veins. Brown lesions appear on stems and petioles. Young leaves show interveinal chlorosis and remain small. Plant growth is stunted. The toxicity in tomato appears when Mn concentration in the soil is >80 mg kg^{-1} and in the plant >1000 mg kg^{-1} (Table 4). The toxicity can be reduced by rapidly sterilizing the soil with a mixture of steam and air at low temperature, by liming the soil to raise pH >7.0, and by applying water soluble P fertilizer, such as triple superphosphate, which reduces Mn availability.

Zinc: Zinc is a constituent of enzyme (carbonic anhydrase) essential for metabolism of nutrients in tomato. Although less common in field soils, deficiency can occur in soilless medium or water culture low in Zn content. The deficiency appears as brown necrotic spot on leaves with slight chlorosis and downward curling of the petioles. High P level in the soil can also reduce Zn availability to tomato and results deficiency [1]. In contrast, high Zn level in the soil can be toxic to tomato. Affected plants are stunted and spindly with smaller leaves. Younger leaves show interveinal chlorosis and purpling undersides. Older leaves curl downwards. Zinc toxicity can result from the application of zinc contaminated organic materials, such as sewage sludge, and using water accumulated on corroded galvanized pipes. Application of water soluble P fertilizer and organic matter low in Zn concentration can reduce the toxicity.

Copper: Although not common in field soils, Cu deficiency can be observed in tomato grown in greenhouse soils or in soilless medium low in Cu content. The symptom appears as curled leaves to form a tubular appearance and curled petioles downwards. Necrotic spotting appears near the veins in leaves. The deficiency can also be observed by the application of excess level of P fertilizer in calcareous soils, which decreases Cu availability to tomato [21]. The deficiency can be reduced by spraying $CuSO_4$ at 5 kg ha^{-1} in the foliage several times during tomato growth. As with Zn, Cu toxicity can result from the application of Cu-contaminated organic materials.

Molybdenum: Molybdenum is needed for N metabolism in tomato. Molybdenum deficiency can occur in acid soils, peats, and soilless compost. The deficiency appears as pale green interveinal chlorosis in older leaves. The deficiency can be reduced by applying $NaMoO_3$ or NH_4MoO_3 at 5 mg L^{-1} in the foliage.

Chloride: Although Cl^- is not an essential element and deficiency does not occur, large concentration of Cl^- in the soil due to high level of soluble salts can damage tomato growth. Excess level of Cl^- in the soil can increase vegetative growth at the cost of fruit reproduction, similar to that increased by high level of NO_3^- in the soil Chloride concentration in the soil is elevated by the application of fertilizers and organic materials containing Cl^-. Application of irrigation and seepage of saline groundwater containing high concentration of Cl^- also increases its level in the soil. Excess Cl^- can be leached by flooding the soil and by improving drainage.

Economical and Environmental Implications of Nutrients

It has been known that mineral nutrition of tomato from application of fertilizers and manures can increase tomato yield and nutrient uptake by several folds compared with no fertilization [13, 31, 32, 39]. In the last few decades, large amount of fertilizers had been applied to the soil to increase crop production without considering the environmental quality. As a result, groundwater had been contaminated with nutrients, such as NO_3 causing health hazard to humans and animals [9, 22, 34], because NO_3 leaching from the soil to the groundwater is directly related with N fertilization rate [26, 27, 33]. Similarly, run off of nutrients, such as N and P, from agricultural lands due to excessive application of animal manures increased eutrophication of lakes and rivers, thereby increasing health hazard to marine animals. As a result, agriculture has been known as a major source of nutrient pollution in the surface and groundwater, although contamination results from several sources, such as industrial wastes, municipal landfills, mining, or septic systems [6, 9, 35]. Another reason for the increased pollution of nutrients in the surface and groundwater from agricultural fields is the inefficiency in plant uptake of nutrients that are applied from manures and fertilizers. Nutrient, such as N, recovered by crops seldom exceeds 70% of the applied amount and averages about 50% for most crops [4, 9, 40]. For vegetable production system, it may be even lower [5, 15]. For example, Sweeney et al. [37] reported that N recovered by tomato from N fertilization in Florida ranged from 32 to 53% while Sainju et al. [31] reported a recovery rate of 13 to 30% with 90 and 180 kg N ha^{-1} in Georgia. As a result, large amount of residual N was left in the soil after tomato harvest in autumn, which increased with increased rate of N fertilization (Fig. 1). This increased the potential for N leaching. Similarly, Abdel-Samad et al.[1] observed that application of P, Fe, and Zn fertilizers to tomato increased their residual levels in the soil after harvest. Because vegetable cropping systems require a greater degree of management and involves a larger input of fertilizer than cereal production systems,

Table 1.Vitamin and mineral content of tomato(100 g edible portion)[25].

Description	Green	Ripe
Ca (mg)	13	13
P (mg)	27	27
Fe (mg)	0.5	0.5
Na (mg)	3	3
K (mg)	244	244
Vitamin A (I.U.)	270	900
Thiamine (mg)	0.06	0.06
Riboflavin (mg)	0.04	0.04
Niacin (mg)	0.5	0.7
Ascorbic acid(mg)	20	23

Table 2. Nutrient contents in tomato leaves and their functions [43].

Nutrient	Content (mg· kg^{-1})	Function
N	48000	Constituent of proteins and amino acids
P	5000	Constituent of nucleic acids
K	55000	Activates enzymes (e.g. pyruvate kinase); regulates pH of tomato fruit.
Mg	5000	Constituent of chlorophyll
Ca	25000	Component of plant cell wall. Affects the permeability of cell membranes
S	16000	Constituent of proteins and amino acids (e.g. methionine)
B	35	Regulates the level of growth substances
Fe	90	Constituent of enzymes (e.g. peroxidase, catalase)
Mn	350	Activates enzymes (e.g. malic)
Cu	15	Constituent of oxidizing enzymes (e.g. phenolase)
Zn	80	Constituent of enzyme (Carbonic anhydrase)
Mo	0.5	Involved in the utilization of NO_3-N (nitrate reductase)

Table 3. Recommended levels of nutrients for tomatoes [7].

	Soil (mg· kg^{-1})		Plant (mg· kg^{-1})	
Nutrients	Desirable	Toxic	Desirable	Toxic
P	60-70	———	4000	———
K	600-700	———	60000	———
Mg	350-700	———	5000	———
Ca	1000	———	12500	———
N	50-100	———	30000-50000	———
B	1.5-2.5	3	40-60	100
Mn	5-20	80	30	1000
pH (no unit)	6.5-7.5	———	———	———
Salt conductivity (mmho· cm^{-1})	80-100	———	———	———

Table 4. Nutrients NPK (kg ha^{-1})removed by tomato for fresh fruit yields of 36.6 t· ha^{-1} in the autumn and 73.6 t· ha^{-1} in the spring in the greenhouse in Ohio, USA [25].

Tomato components	N		P		K	
	Sand	Silt and Clay	Sand	Silt and Clay	Sand	Silt and Clay
Fruit						
Fall	89	91	19	11	184	186
Spring	177	201	38	43	367	390
Vines						
Fall	99	90	29	22	147	149
Spring	164	128	58	36	248	211
Total						
Fall	188	181	48	33	331	335
Spring	341	329	96	79	615	601
Mean	244.5	255	72	56	473	468

Table 5. Effects of tillage and N fertilization on tomato fruit number, fresh and dry yield, and N concentration and uptake in 1996 and 1997 [31].

	Fruit no. /plant		Yield (Mg· ha^{-1}) Fresh		Dry		N conc. —(g· kg^{-1})—		N uptake —(kg· ha^{-1})—	
Treatment	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997
Tillage[z]										
NT	18.7 a[y]	40.3 a	35.0 a	32.1 a	1.32 a	1.68 a	38.5 a	40.9 a	50.6 a	69.1 a
CH	25.7 a	34.9 a	66.4 b	33.5 a	2.48 b	1.69 a	37.8 a	37.9 a	93.8 b	64.3 a
MB	25.9 a	39.8 a	62.9 b	30.5 a	2.44 b	1.66 a	35.8 a	38.8 a	86.9 b	63.1 a
N fertilization (kg· ha^{-1})										
0	22.8 a	36.7 a	49.5 a	26.6 a	1.83 a	1.32 a	38.0 a	39.1 a	69.1 a	51.8 a
90	22.6 a	40.2 a	58.1 b	36.0 b	2.20 b	1.86 b	37.1 a	39.9 a	82.4 b	73.1 b
180	25.0 a	38.1 a	56.6 b	33.6 b	2.22 b	1.87 b	37.0 a	38.7 a	80.0 b	71.7 b
Significance[x]										
Tillage	NS	NS	**	NS	**	NS	NS	NS	**	NS
N fertilization NS	NS	*	**	*	***	NS	NS	*	***	

[z] NT denotes no-till; CH, chisel plowing; and MB, moldboard plowing.

[y] Mean separation within columns of a treatment by the least square means test, *P*?0 05.

[x] Sources of variation that were not significant are excluded.; NS, *, **, and *** Not significant or significant at *P*?0.05, 0.01, and 0.001, respectively.

Table 6. The effects of cover crops and N fertilization on marketable tomato fresh fruit yield, biomass (leaves + stems + fruits dry wt.), and N uptake in 1996 and 1997 [32].

Treatment	Fruit yield ($Mg \cdot ha^{-1}$)		Biomass ($Mg \cdot ha^{-1}$)		N uptake ($kg \cdot ha^{-1}$)	
	1996	1997	1996	1997	1996	1997
Rye	19.0b[a]	13.6c	1.51b	1.28c	30.9b	32.8c
Hairy vetch	40.2a	31.5a	3.14a	2.92a	75.8a	78.2a
Crimson clover	40.9a	30.0a	3.22a	2.80a	78.8a	74.6a
0 kg N ha^{-1}	20.0b	17.3bc	1.60b	1.65bc	35.3b	44.4bc
90 kg N ha^{-1}	39.1a	27.9ab	3.03a	2.82a	72.9a	76.0a
180 kg N ha^{-1}	43.1a	27.0ab	3.39a	2.33ab	83.0a	63.5ab
Significance						
Treatment (T)	**		**			**
Year (Y)	*		*			NS
Tx Y	**		*			**

[a] Within a column, numbers followed by different letter are significantly different (*P*<0.05, least square means test).
[b] Not significant.; * Significant at *P*<0.05.; ** Significant at *P*<0.01.

Table 7. Effects of K on tomato fruit quality [43].

Tomato quality	Variety	K rate ($kg \cdot ha^{-1}$) 407	813	1626
% irregularly shaped fruit	J 168	17	11	9
	Moneymaker	22	14	11
% hollow fruit	J 168	56	23	10
	Moneymaker	32	14	9
Titratable acidity †	J 168	5.4	6.9	9.1
	Moneymaker	6.0	7.2	8.0

† Acidity of the juices expressed from frozen fruit (cmol kg^{-1})

Table 8. The effect of N, P, K, Mg, and B on the yield and morphological and quality characteristics of industrial tomatoes [13].

Nutrient ($kg \cdot ha^{-1}$)					Fruit characteristics						
N	P	K	Mg	B	Yield ($t \cdot ha^{-1}$)	Fresh weight (g)	Length (cm)	Width (cm)	Pericarp thickness (cm)	Dry matter (%)	NO_3 conc. ($mg \cdot kg^{-1}$)
0	0	0	0	0	81.5	142	5.4	6.5	0.5	4.2	7.0
100	100	150	0	0	85.3	166	5.3	6.5	0.5	4.5	7.5
100	100	150	1	0	91.1	163	5.4	6.6	0.5	4.4	7.5
100	100	150	0	0.5	89.2	152	5.5	6.8	0.5	4.2	7.5
100	100	150	1	0.5	97.5	152	5.4	6.7	0.5	4.2	6.5

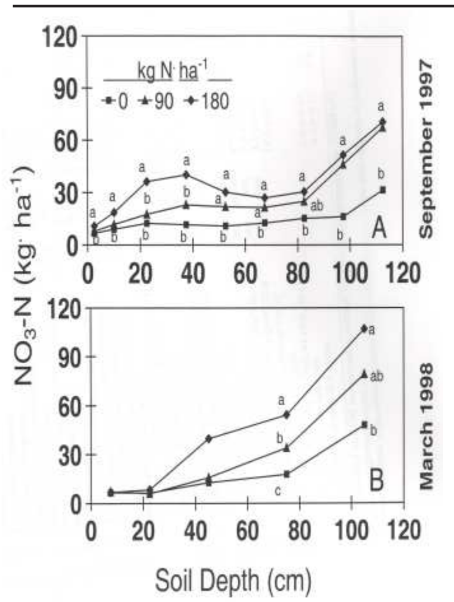

Figure 1. Soil NO_3-N with depth in the autumn (September 1997) and spring (March 1998) influenced by N fertilization. Nitrate content at a particular depth is plotted at the mid-point of the depth range. Symbols followed by different letter at a particular depth are significantly different at *P*=0.05 by the least square means test [30].

the potential for nutrient loss through erosion, surface runoff, and leaching in vegetable production systems remains even greater [28]. Greater rate of fertilization than that needed by plants can cause both economic loss and environmental damage. Because fertilization increases the cost of tomato production, increasing the rate of fertilization without additional yield further increases the cost. Sainju et al. [31, 32] observed that 90 kg $N \cdot ha^{-1}$ can produce as much tomato yield and N uptake as 180 kg $N \cdot ha^{-1}$ did, both of which produced greater tomato yield, dry matter weight, and N uptake than 0 kg $N \cdot ha^{-1}$ (Tables 5 and 6). In contrast, 180 kg $N \cdot ha^{-1}$ increased residual soil N accumulation and movement compared with 90 kg N ha^{-1} under tomato (Fig. 1). This indicates that reduced rate of N fertilization not only produced sustainable tomato yield but also reduced the cost of fertilization and the potential for N leaching and contamination in the groundwater. Research is needed to see if the reduced rate of fertilization for other nutrients can also sustain tomato yield and improve environmental quality. Because the amount of fertilizer requirement for tomato varies with soil type and environmental conditions, analysis of soil and plant samples needs to be conducted every year before applying fertilizers to determine their proper rate so that both the cost of fertilization and environmental degradation can be reduced. As rapid release of nutrients from fertilizers can increase the potential for groundwater contamination if the fertilizer-use efficiency for tomato is low, alternative sources of nutrient application, such as cover crops that release nutrients slowly, can be used to reduce the contamination [29]. Winter cover crops can recycle post-harvest soil residual nutrients that may be lost from erosion, runoff, and leaching and increase soil organic matter concentration [18, 29]. Legume cover crops can also fix N from the atmosphere and supply the N needs of the succeeding crop, thereby reducing the rate of N fertilization [17, 20]. Sainju et al. [31, 32] observed that legume cover crops, such as hairy vetch and crimson clover, produced tomato yield and N uptake similar to those did by 90 and 180 kg N ha^{-1} (Tables 5 and 6). Although cover crops have benefits in improving soil and water quality and reducing the cost of N fertilization, their economical and social costs needs to evaluated before using them as a substitute for N fertilizer. For example, buying cover crop seeds and cultivating them can raise the total cost of tomato production. Farmers' acceptance to such approaches needs to be evaluated because the system may not fit in crop rotation. Climatic factor may be another obstacle for cover crop production because cover crops are usually grown in winter when no other crops are grown. Regions which do not have mild winter may not support cover crop growth.

References

[1] Abdel-Samad, S., Ismail, E.A.M., El-Beltagy, A.S., and Abou-Hadid, A.F. 1996a. Tomato growth in calcareous soils in relation to forms and levels of some macro- and micronutrients. Acta Hort. **434:** 85-94.

[2] Abdel-Samad, S., Ismail, E.A.M., El-Beltagy, A.S., and Abou-Hadid, A.F. 1996b. Iron, zinc and phosphorus relationships in the nutritional status of tomato seedlings grown on sandy soils. Acta Hort. **434:** 77-84.

[3] Adb-Alla, A.M., Adam, S.M., Abou-Hadid, A.F., and Iman, S.S.B. 1996. Temperature and fertilizer effects on tomato productivity. Acta Hort. **434:** 113-119.

[4] Allison, F.E. 1955. The enigma of soil nitrogen balance sheets. Adv. Agron. **7,** 213-250.

[5] Errebhi, M., Rosen, C.J., Gupta, S.C., and Birong, D.E. 1998. Potato yield response and nitrogen leaching as influenced by nitrogen management. Agron. J. **90:** 10-15.

[6] Ferguson, R.B., Shapiro, C.A., Hergert, G.W., Kranz, W.L., Klocke, N.L., and Krull, D.H. 1991. Nitrogen and irrigation management practices to minimize nitrate leaching from irrigated corn. J. Prod. Agric. **4:** 186-192.

[7] Gallgher, P.A. 1972. Potassium nutrition of tomatoes. Proc. Provisional Glasshouse Conference, Dublin, England. p. 13-18.

[8] Gould, W.A. 1983. Tomato Production, Processing, and Quality Evaluation. AVI Publishing Co., Westport, CT.

[9] Hallberg, G.R. 1989. Nitrate in groundwater in the United States. In: R.F. Follett (ed.). Nitrogen Management and Groundwater Protection. Elsevier, Amsterdam. p. 35-74.

[10] Hallberg, G. R., Libra, R.D., and Hoyer, B.E. 1985. Non-point source contamination of groundwater in Karst carbonate aquifers in Iowa. Perspectives on non-point source pollution. United States Environmental Protection Agency, Washington, D.C.

[11] Hayslip, N.C., and Iley, J.R. 1967. Influence of potassium fertilizer on severity of tomato graywall. Florida Agricultural Experiment Station Journal Series No. 2840. p. 183-186.

[12] Kaniszewki, S., and Elkner, K. 1990. Effect of nitrogen fertilization and irrigation on yield and fruit quality of two stated tomato cultivars. Hort. Abstract, p. 406.

[13] Kocevsky, G.J.V., Jakimov, N.D., Kekic, M.M., and Koleva, R.L. 1996. The effect of nitrogen, phosphorus, potassium, magnesium, and boron on the yield, morphological, and quality characteristics of industrial tomatoes. Acta Hort. **462:** 183-186.

[14] Kucuk, O. 2001. Phase II randomized clinical trial of lycopene supplementation before radical prostatectomy. Cancer Epidem. Biom. Prev. **10:** 861-868.

[15] Lowrance, R., and Smittle, D. 1988. Nitrogen cycling in a multiple crop-vegetable production system. J. Environ. Qual. **17**, 158-162.

[16] Maynard, D.N., Barker, A.V., and Lachman, W.H. 1966. Ammonium-induced stem and leaf lesions of tomato plants. Proc. Amer. Soc. Hort. Sci. **88:** 516.

[17] McVay, K.A., Radcliffe, D.E., and Hargrove, W.L. 1989. Winter legume effects on soil properties and nitrogen fertilizer requirements. Soil Sci. Soc. Amer. J. **53:** 1856-1862.

[18] Meisinger, J.J., Hargrove, W.L., Mikkelsen, Jr., R.L., Williams, J.R., and Benson, V.W. 1991. Effects of cover crops on groundwater quality. In: W.L. Hargrove (ed.). Cover Crops for Clean Water. Soil and Water Conservation Society, Ankeny, IA. p. 57-68.

[19] Miliev, K. 1966. Effects of two nutrient solutions at different conductivities on same growth parameters of tomato plants. Acta Hort. **462:** 641-648.

[20] Morris, T.F., Blackmer, A.M., and El-Hout, N.M. 1993. Optimal rates of nitrogen fertilization for first year corn after alfalfa. J. Prod. Agric. **6:** 344-350.

[21] Murphy, L.S., Ellis, R. Jr., and Adriano, D.C. 1980. Phosphorus application interaction effects on crop production. J. Plant Nutri. **3**, 593-613.

[22] National Research Council. 1978. Occurrence and transport of nitrate in the environment. In: Nitrates: An Environmental Assessment. National Academic of Science, Washington, D.C., p. 103-605.

[23] Needham, P. 1973. Nutritional disorders. In: The U.K. Tomato Manual. Grower Books, London.

[24] Nelson, W.L. 1978. Phosphorus and moisture. In Phosphorus for Agriculture. Phosphate and Potash Institute, Atlanta, GA. p. 160.

[25] Nonnecke, I.N. 1989. Vegetable Production. Van Nostrand Reinhold, New York.

[26] Owens, L.B., Edwards, W.M., and Van Keuren, P.W. 1994. Groundwater nitrate levels under fertilized grass and grass-legume pasture. J. Environ. Qual. **23:** 752-758.

[27] Pang, X.P., Gupta, S.C., Moncrief, J.F., Rosen, C.J., and Cheng, H.H. 1998. Evaluation of nitrate leaching potential on Minnesota glacial outwash soils using the CERES-maize model. J. Environ. Qual. **27:** 75-85.

[28] Power, J.F., and Schepers, J.S. 1989. Nitrate contamination of groundwater in North America. Agric. Ecosys. Environ. **26:** 165-187.

[29] Sainju, U.M., and Singh, B.P. 1997. Winter cover crops for sustainable agricultural systems: Influence on soil properties, water quality, and crop yields. HortScience **32:** 21-28.

[30] Sainju, U.M., Singh, B.P., Rahman, S., and Reddy, V.R. 1999. Soil nitrate-nitrogen under tomato following tillage, cover cropping, and nitrogen fertilization. J. Environ. Qual. **28**, 1837-1844.

[31] Sainju, U.M., Singh, B.P., Rahman, S., and Reddy, V.R. 2000a. Tillage, cover crop, and nitrogen fertilization influence tomato yield and nitrogen uptake. HortScience **35**, 217-221.

[32] Sainju, U.M., Singh, B.P., Rahman, S., and Reddy, V.R. 2000b. Tomato root growth is influenced by tillage, cover cropping, and nitrogen fertilization. HortScience **35**, 78-82.
[33] Sexton, B.T., Moncrief, J.F., Rosen, C.J., Gupta, S.C., and Cheng, H.H. 1996. Optimizing nitrogen and irrigation inputs for corn based on nitrate leaching and yield on a coarse-textured soil. J. Environ. Qual. **25**, 982-992.
[34] Stanford, G. 1982. Assessment of soil nitrogen availability. In: F.J. Stevenson (ed.). Nitrogen in Agricultural Soils. Soil Science Society of America, Madison, WI. p. 651-658.
[35] Stanley, C.D., Green, R.E., Khan, M.A., and Santo, L.T. 1990. Nitrogen fertilization rate and soil nitrate distribution for micro-irrigated sugarcane. Soil Sci. Soc. Amer. J. **54**, 217-222.
[36] Su, N.R. 1974. Experiments involving the use of sulfur-coated fertilizer for corn and tomatoes. Agronomic Cooperators Workshop, Muscles Shoals, AL, 6-8 Nov. 1974.
[37] Sweeney, D.W., Graetz, D.A., Bottcher, A.B., Locaccio, S.J., and Campbell, K.L. 1987. Tomato yield and nitrogen recovery as influenced by irrigation method, nitrogen source, and mulch. HortScience **22**, 27-29.
[38] United State Department of Agriculture (USDA). 1963. Composition of Foods. USDA Agricultural Handbook No. 7.
[39] Varis, S., and George, R.A.T. 1985. The influence of mineral nutrition on fruit yield, seed yield, and quality in tomato. J. Hort. Sci. **60**, 373-376.
[40] Viets, F.G. 1965. The plant's need for and use of nitrogen. In: W.V. Bartholomew and F.E. Clark (eds.). Soil Nitrogen. Soil Science Society of America Journal, Madison, WI. p. 503-549.
[41] von Uexkull, H.R. 1979. Tomato nutrition and fertilizer requirements in the tropics. First International Symposium on Tropical Tomato. p. 65-78.
[42] Wiersum, L.K. 1966. Calcium content of fruits and storage tissues in relation to mode of water supply. Acta Bot. Neerl **15**, 406-418.
[43] Winsor, G.W. 1973. Nutrition. In: The U.K. Tomato Manual. Grower Books, London.
[44] Winsor, G.W., Davis, J.N., and Long, M.I.E, 1967. The effects of nitrogen, phosphorus, potassium, magnesium, and lime in factorial combination on the yields of tomatoes. J. Hort. Sci. **42**, 277-288.
[45] Zobel, M.B. 1966. Mechanization of tomato production. Proc. National Conference on Tomatoes. Department of Horticulture, Perdue University, National Canners Association, Lafayette, IN, December, 1966.