Turk J Agric For
27 (2003) 323-328

Nitrogen Fertiliser Recovery and Yield Response of Greenhouse Grown and Fertigated Tomato to Root - Zone Soil Water Tension

Cevat KIRDA*, Nafi BAYTORUN, M. Rıfat DERİCİ, H. Yıldız DAŞGAN
Çukurova University, Faculty of Agriculture, 01330 Adana - TURKEY

Çağatay TANRIVERDİ
Kahramanmaraş Sütçü İmam Üniversity, Faculty of Agriculture, 46060 Kahramanmaraş - TURKEY

Zekai GÜMÜŞ
Mustafa Kemal University, Faculty of Agriculture, 31040 Hatay - TURKEY

Received: 16.06.2003

Abstract: Tomatoes were grown in a plastic greenhouse under 2 irrigation programmes and four N-fertiliser concentrations (0, 100, 150 and 200 mg N l^{-1}) of irrigation water. P and K concentrations were kept constant at 30 and 200 mg l^{-1}, respectively, for all N treatments. A drip irrigation system with single laterals centred between the plant rows, spaced 50 cm apart was used for irrigation as well as for feeding fertiliser solution (i.e. fertigation) during the experiment. Tensiometers, installed in 3 replicates at 45 cm soil depth and centred mid-way between 2 plants in rows, were used for irrigation scheduling. Two irrigation programmes, controlled through continuous monitoring of root-zone soil-water tension, were used as irrigation treatments. In one of the treatments, irrigation scheduling was based on a maximum soil-water tension of 50 kPa during the entire season. In the second treatment, soil-water tension to initiate irrigation was initially high (70 kPa), until fruit stetting, and it fell down to 50 kPa, later in the season. ^{15}N labelled urea was used in one of the N-concentration treatments (150 mg N l^{-1}) to estimate tomato N-fertiliser recovery. The results showed that tomato yield was not influenced significantly by irrigation treatments, although the irrigation treatment of low soil-water tension (≤ 50 kPa), maintained throughout the season, gave higher yield. Exposing tomatoes to high soil water stress during the early growth stage, first 70 kPa then dropping to 50 kPa, promotes proportionally higher uptake of soil N, and thus reduces the recovery of applied N-fertiliser. However, when low soil water tension (≤50 kPa) was maintained throughout the season, N-fertiliser recovery was 22.4% higher compared with when high soil water-tension prevailed until mid season. As for the effects of N concentration of the feeding solution, tomatoes showed a statistically significant ($P \le 0.05$) fruit-yield response to varying N concentrations. The feeding-solution-N concentration giving the highest tomato fruit yield was about 120 mg N l^{-1} as estimated using a N-concentration yield-response function.

Key Words: Fertigation, N-fertiliser recovery, N-fertiliser concentration, ^{15}N, soil-water tension, tomato

Fertigasyon Tekniği İle Serada Yetiştirilen Domatesin, Kök Bölgesi Topraksuyu Tansiyonuna Verim Tepkisi ve Azotlu Gübre Alımı

Özet: Domates iki sulama programı ve dört farklı sulama suyu N'lu gübre konsantrasyonu (0, 100, 150 ve 200 mg N l^{-1}) kullanılarak plastik serada yetiştirildi. Tüm N konularında, sulama suyu fosfor ve potasyum konsantrasyonları, sıra ile 30 ve 200 mg l^{-1} olarak sabit tutulmuştur. Araştırmada, 50 cm aralıklı çift bitki sıralarını ortalamak üzere yerleştirilmiş tek lateralli damla sulama sistemi, hem sulama ve hemde gübre enjekte etmek üzere kullanılmıştır. Denemede bitki kök bölgesi toprak suyu tansiyonuna göre denetlenen iki sulama programı uygulanmıştır. Konulardan birinde, topraksuyu tansiyonu 50 kPa'a eriştiğinde sulama yapılmış ve anılan ölçüt tüm mevsim boyunca ayni kalmıştır. İkinci sulama konusunda ise, ilk meyve dökümüne kadar (seraya şaşırtmadan 71 gün sonra) toprak suyu tansiyonu 70 kPa erişince sulama yapılırken, geri kalan zamanda ise tansyiyon 50 kPa'a indirilmiştir. Azot konsantrasyonu konularından birinde (150 mg N l^{-1}), ^{15}N ile zenginleştirişniş üre kullanılarak domatesin N'lu gübre kullanma randımanı hesaplandı. Elde edilen sonuçların gösterdiğine göre, her ne kadar istatiksel olarak önemli olmasa da, toprak su tansiyonunun düşük (≤50 kPa) olarak tutulduğu konuda domates verimi daha fazla çıkmıştır. Domates bitkisinin başlangıç döneminde su stresi altında tutulması, toprak suyu tansiyonunun önce 70 kPa daha sonra 50 kPa'a indirilmesi, göreli olarak daha fazla toprak-azotu alınmasını ve dolayısiyle N'lu gübre alımını azaltan bir etkiye neden olmuştur. Ancak, toprak suyu tansiyonunun tüm mevsim boyunca düşük bir değerde (≤50 kPa) tutulduğu konu altında N'lu gübre kullanma randımanı, mevsim ortasına kadar tansiyonun yüksek tutulduğu (≤70 kPa) konuya kıyasla % 22.4 daha yüksek çıkmıştır. Azotlu gübre konsantrasyonu konularının domates verimine etkisi $P \le 0.05$ düzeyinde önemli bulunmuştur. Maksimum domates verimi için sulama suyu N konsantrosyonunun 120 mg N l^{-1} cıvarında olması gerektiği, verim N-konsantrasyonu ilişkisinden, hesaplanmıştır.

Anahtar Sözcükler: Fertigasyon, N-lu gübre alımı, N-lu gübre konsantrasyonu, ^{15}N, toprak suyu tansiyonu, domates

* Correspondence to: ckirda@cu.edu.tr

Introduction

Irrigation systems, which facilitate trouble-free management and full control of fertiliser applications, are now in common use in many countries. Standard sprinkler irrigation systems, mini sprinklers and drip irrigation systems are among the latest irrigation technologies which can be used conveniently for the application of fertilisers with irrigation water (Bresler, 1977; Elfving, 1988; Papadopoulos, 1988). Through the use of drip irrigation systems, plant nutrients can be applied, when needed, at required concentrations in the wetting zone of the drippers where plant roots are the most active. With fertigation, not only does crop water-use efficiency increase, but significant savings in fertiliser use can also be achieved (Tumbare et al., 1999). The application of fertilisers through fertigation can conveniently be matched with plant requirements, depending on the crop growth stage (Kovach, 1983). Fertiliser recovery under fertigation is the highest, and nearly zero residual fertiliser salinity remains (Miller et al., 1981) in the soil after the harvesting of crops if the system is designed well and managed properly.

Irrigation management is an important issue which not only has a direct influence on quality; it may affect indirectly the yield response of crops to fertiliser applications. Furthermore, depending on irrigation method and management followed, crop fertiliser recovery - uptake of applied fertilisers - may differ. It is important that while crop productivity increases with high-input agricultural practices, such as protected agriculture, fertilisers must be applied with environment-friendly methods, leaving the least residue in the soil.

This study aimed to determine the fruit yield response of fertigated tomato to different N-fertiliser concentrations of feeding solution and to assess N-fertiliser recovery under 2 irrigation programmes where plant-root-zone soil-water tension was different.

Materials and Methods

Experiments were carried out in plastic greenhouses of Research Farm at Faculty of Agriculture, Çukurova University, Adana, Turkey. The plastic houses, oriented in north-south direction, were 12 x 24 m in size and the cover material was UV + IR + antifog added polyethylene.

The tomato cultivar used was F144 Fantastic. The experimental soil in the greenhouse was classified as Palexerollic chromoxeret with heavy textured clay soil overlaying medium textured sandy clay sub-soil. The soil had medium permeability with a high water retention capacity (360 mm per 100 cm depth of soil at field capacity).

A split-plot experimental design with 4 replicates, consisting of 2 irrigation programmes, designated as the main treatments, and 4 N fertiliser concentrations (0, 100, 150 and 200 mg N l^{-1}), was used (Table 1). P and K concentrations were 30 and 200 mg l^{-1} of irrigation water, respectively, and were kept constant for all the N treatments. The forms of the fertilisers used were urea, phosphoric acid and potassium sulphate for N, P and K, respectively. Total sub-plots were 32, each having 16 plants, arranged as double rows with a planting space of 50 cm in rows. Each replicate contained 2 rows of 8 plants (Figure 1). Fruit yields of 12 plants, excluding the 2 plants at the extreme ends of the rows, were recorded during harvest.

A drip irrigation system with single laterals centred between the 2 rows of plants was used (Figure 1). The

Table 1. Description of the treatments.

Irrigation treatments	
1. Low soil water tension, A	Maximum allowed tension: 50 kPa
2. High soil water tension, B	Maximum allowed tension: 70 kPa until fruit setting, then reduced to 50 kPa
N-fertiliser treatments	
0, 100, 150 and 200 mg N l^{-1} of irrigation water applied in every irrigation	

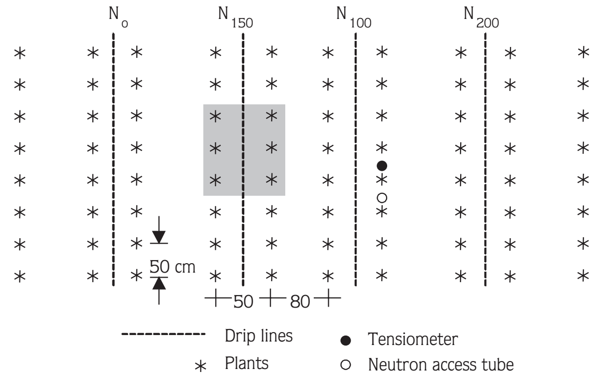

Figure 1. Random arrangement of N-concentration treatments under one of the main irrigation treatments. The plant rows with no N-concentration designation are the guard rows. The shaded plants are those fed with labelled ^{15}N.

spacing of the drippers with a flow rate of 2 l h^{-1} was 30 cm. A wet band of approximately 70 cm width, covering the 2 rows of plants, was formed during irrigations. Irrigation scheduling was controlled using tensiometers, as they were widely used in numerous earlier studies (e.g., Clark et al., 1991; Paramasivam et al., 2000). The tensiometers were installed at 45 cm soil depths and centred between the 2 plants in rows. Soil-water-tension measurements (averages of 3 replicate) were used as criteria for irrigation scheduling, followed in the 2 different irrigation treatments of low (A) and high soil water tensions (B) (Table 1). The high soil water tension treatment (B) for the tomato crop was applied until mid season, 71 days after transplanting at initial flower setting stage. During the remaining period, the soil water tensions of the 2 treatments (A and B) were the same (50 kPa). Additionally, neutron access tubes were installed in 3 replicates, again centred between the 2 plants in rows. The access tubes were used to measure soil water content distribution profiles, before and after irrigation, using a neutron gauge (CPN 503DR), which allowed adjustment of the irrigation water requirement for preventing deep percolation.

N-fertiliser recovery was studied to assess if irrigation scheduling would influence N fertiliser uptake. For this propose, only 1 N concentration treatment (150 mg N l^{-1}) was used. The data were analysed following the procedure of randomised complete block design with 2 irrigation treatments of 4 replicates, excluding N-concentration treatments. Three drippers of the drip line in the 150 mg N l^{-1} treatment were blocked and a separate feeding system was used for the 3 pairs of double rowed plants (i.e. isotope plants, see Figure 1) for the application of water and fertiliser solution. Urea labelled with 0.578% ^{15}N atom excess was applied to assess N fertiliser recovery using the isotope dilution technique, which was used earlier in numerous other studies (e.g., Masuda et al., 1996; Al-Rawahy et al., 1992; Jena et al., 1988). Of the 3 pairs of plants fed with ^{15}N labelled urea, 2 plants in the centre were cut off at the first harvest (Figure 1), 125 days after transplanting. The cut samples were separated into vegetative parts and fruit, which were dried and ground and then analysed for total nitrogen and $^{15}N/^{14}N$ ratio at the International Atomic Energy Agency's Laboratories, Seibersdorf, Austria. Tomato-crop N yield, % N derived from fertiliser-N (%Ndff) and N-fertiliser recovery (stems plus fruit) were calculated using the isotope data and following the procedure described by Zapata (1990) and more recently by Kirda et al. (2001). Before the experiment was implemented, the greenhouse soil was leached with 500 mm water application to minimise the likely effects of mineral-N residue from the earlier years on the N-recovery study. After leaching, NO_3-N content within the 5-cm surface layer was in the order of 7 to 10 mg kg^{-1}, with the exception of a few spots at 30 to 40 mg kg^{-1}. NH_4-N content was only in trace amounts, nearly 10 times less than NO_3-N.

The greenhouse was not heated but was frost protected. The heating system worked only when the outside temperature was below 5 °C, as was normally practised by the growers in the region.

Results and Discussion

Yield

It is generally believed that the tomato plant, which is kept under some degree of water stress during the early growth stage, could develop tolerance to water stress at later stages. Tomato plants that have undergone water stress during early growing stages increase their root-to-foliage ratio thereby lowering the threshold leaf-water potential for stomatal closure. Under the described conditions, leaf chlorophyll content and stomatal density, which could enhance the photosynthetic rate, would increase (Iljin, 1957; Steudle et al., 1977). It is important therefore for greenhouse-grown tomatoes to develop deep root systems to exploit a larger volume of soil for nutrients and water. The described condition can be obtained through withholding irrigation during the early growth stages, until the first flower setting (Rudich and Luchinsky, 1994). Although adaptation to water stress may prove useful under situations where plants might have undergone water stress and received inadequate fertilisation, the results in our experiment clearly indicate that this does not occur under fertigation where both soil water content and nutrient concentrations within the plant rooting zone can be controlled and maintained in accordance with the plant's requirements. The yield under the irrigation programme, where the maximum soil water tension allowed was 70 kPa until the first-flower-setting stage (i.e. treatment B), was lower but not statistically significant (Table 2) compared with low, 50 kPa, soil-water-tension treatment (i.e. treatment A) (Figure 2). In concert with our findings, earlier reported studies had also shown that open-field-table tomatoes (Rendon and Ambri, 1980) and processing tomatoes (Yrisarry et al., 1993) gave higher fruit yields under low soil-water tensions, maintained during the development and maturation stages, compared with low yields obtained under high soil-water tensions.

Only N-concentration treatments had a statistically significant effect ($P \leq 0.05$) on tomato fruit yield (Table 2). N concentration giving the highest yield was not influenced significantly by the irrigation programme followed. Thompson et al. (2000) have reported similar findings for sub-surface drip-irrigated cauliflower, which gave a better yield response to N-fertiliser rates than to differences in irrigation management. Tomato fruit yield's response to the N concentration of the feeding solution could typically be described with a second-degree polynomial curve, fitted to the pooled data of the 2 irrigation treatments (Figure 2). The feeding solution N-concentration giving the highest tomato fruit yield was about 120 mg N l^{-1} as estimated using the fitted yield response function.

Fertiliser recovery

Tomato crop N-fertiliser uptake attributes such as N yield and percent N derived from the applied fertiliser (% Ndff) and N fertiliser recovery and the like are shown in Table 3. The low recovery of the applied N-fertiliser, of the order 40 to 50%, can be attributed to the rapid immobilisation of N through microbiologic activity which causes tying up of mineral N as organic matter (Mohammad et al., 1999). Additionally, applied N-

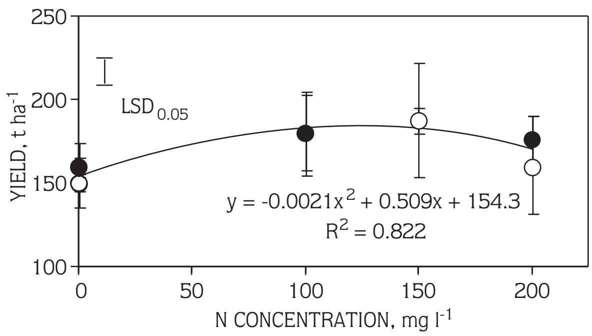

Figure 2. Fertigated tomato fruit yield response to N concentration of feeding solution, with pooled data from the 2 different irrigation programmes. Data points of solid and plain circles represent mean values (n = 4) ± se of treatments A and B, respectively.

Table 2. Tomato yield (t ha^{-1}). The yield data for N concentration and irrigation treatments represent mean values (n = 4 and n = 16, respectively) ± se.

N Concentration mg N l^{-1}	Irrigation treatments		Significance, LSD (≤ 0.05)
	A, 50 kPa	B, 70/50 kPa	
0	159.5 ± 14.5	150.4 ±1 5.1	
100	179.8 ± 24.6	180.0 ± 22.4	
150	187.2 ± 7.8	187.9 ± 34.0	16.9
200	175.9 ± 14.6	161.0 ± 29.5	
Mean	175.6 ± 7.8	169.8 ± 12.4	NS

Table 3. N-fertiliser recovery and related data obtained for tomatoes grown under 2 irrigation programmes. Data represent mean values (n = 4) ± se.

Irrigation treatment	Total dry matter, (1)	N yield, (2)	% Ndff, (3)	% N fertiliser recovery, (4)
A, 55 kPa	200.0 ± 11.7	4.1 ± 0.5	31.2 ± 0.6	53.5 ± 3.3
B, 70/55 kPa	178.4 ± 7.2	4.8 ± 0.8	24.0 ± 0.7	43.7 ± 3.1
Significance, LSD (≤0.05)	NS	NS	2.7	NS

(1) Above ground total dry matter, g.plant^{-1}; (2) N yield, g N.plant^{-1}; (3) Proportion of fertiliser N in total N yield produced; (4) Proportion of applied fertiliser N recovered.

fertiliser might have had so-called priming effect on increasing the uptake of soil N (Fried and Broeshart, 1974) through enhanced root proliferation, which in turn increases soil volume for exploitation of water and nutrients. Leaching loss of N-fertiliser does not seem to be very likely because the wetting depth during irrigation was maintained within a maximum depth of 80 cm, which was controlled and monitored with neutron-gauge water measurements.

The N fertiliser recovery of tomatoes exposed to water stress imposed during the early growth stage (i.e. treatment B) was lower than that in crops which experienced no water stress and were grown under the same soil water tension (i.e. treatment A) throughout the growing season (Table 3). Having no significant differences regarding fruit yield (Figure 2, Table 2), total dry matter and N yield (Table 3) confirms that tomato roots were most probably extended deeper under high water stress conditions (70 kPa) than under low stress conditions (50 kPa). However, we have no data to substantiate the suggested root behaviour. Al-Rawahy et al. (1992) had earlier shown that tomato nutrient uptake is often impaired under salt, water or both stress conditions. Similarly, in our study, the tomato crop, when under water stress, took up proportionally less N fertiliser and more soil N, compared to irrigation treatment with a low water stress maintained throughout the season.

Conclusions

Exposing a tomato crop to variable soil-water tension, first high at 70 kPa, reduced later to a lower value of 50 kPa, does not give any yield benefit compared with the situation where maximum allowable soil-water tension was kept constant at a low value of 50 kPa. Yield response to the N concentration of feeding solution can adequately be described with second-degree polynomial equations. The feeding solution N concentration giving the highest tomatoes yield was about 120 mg N l^{-1}.

N fertiliser recovery, assessed with ^{15}N labelled urea, was influenced strongly by the irrigation programme followed. N-fertiliser recovery under the irrigation programme, allowing a maximum soil water tension of 50 kPa throughout the growing season (treatment A) was higher than with the irrigation treatment where the soil water tension was kept higher (70 kPa, treatment B) until mid season (Table 3). In other words, water stress adversely affects the N-fertiliser recovery of a tomato crop.

Acknowledgements

This work was financially supported by the Scientific and Technical Research Council of Turkey (TÜBİTAK) through Project TOGTAG-1272. Thanks are due to the Technical Staff at the IAEA's Agricultural Laboratory, Seibersdorf, Austria, for ^{15}N analyses.

References

Al-Rawahy, S.A., J.L. Stroehlein and M. Pessarakli. 1992. Dry-matter yield and nitrogen-15, Na^+, Cl^-, and K^+ content of tomatoes under sodium chloride stress. J. Plant Nutrition, 15: 341-358.

Bresler, E. 1977. Trickle-drip irrigation. Principles and application to soil-water management. Advances in Agronomy 29: 343-393.

Clark, G.A., C.D. Stanley, D.N. Maynard, G.J. Hochmuth, E.A. Hanlon and D.Z. Haman. 1991. Water and fertiliser management of microirrigated fresh tomatoes. Tans. ASAE 34: 429-435.

Elfving, D.C. 1982. Crop response to trickle irrigation. Horticulture Reviews 4: 1-48.

Fried, M. and K. Broeshart, 1974. Priming effect of N fertilisers on soil N. Soil Sci. Soc. Am. 38: 858-862.

Iljin, W.S. 1957. Drought resistance: Plant and processes. Ann. Rev. Plant Physiol. 8: 257-274.

Jena, D., C. Misra and D.R. Nielsen. 1988. Fate of ^{15}N tagged urea leached with infiltrating water under pigenpea and rice plus pigenpea intercropping systems. J. Indian Soc. Soil. Sci. 36: 211-218.

Kirda, C., M.R. Derici and J.S. Schepers. 2001. Yield response and N-fertiliser recovery of rainfed wheat growing in the Mediterranean region. Field Crops Res. 71: 113-122.

Kovach, S.P. 1983. Injection of fertilisers into drip systems for vegetables. Citrus and Vegetable Magazine 14: 40-47.

Masuda, M., H. Hasegawa and M. Nomura. 1996. Diurnal translocation of nitrogen (^{15}N) and calcium (^{45}Ca) from tomatoes (*Lycopersicum esculentum*) roots to fruiting trusses. J. Japanese Soc. Hort. Sci., 65: 571-577.

Miller, R.J., D.E. Rolston, R.S. Rauschkolb and D.W. Wolfe. 1981. Labelled nitrogen uptake by drip irrigated tomatoes. Agronomy J. 73: 265-270.

Mohammad, M.J., S. Zuraiqi, W. Quasmeh and I. Papadopoulos. 1999. Yield response and nitrogen utilization efficiency by drip-irrigated potato. Nutr. Cycl. Agroecosys. 54: 243-249.

Papadopoulos, I. 1987. Nitrogen fertigation of greenhouse-grown tomato. Communications in Soil Sci. and Plant Analysis 18: 897-907.

Paramasivam, S., A.K. Alva and A. Fares. 2000. An evaluation of soil water status using tensiometers in a sandy soil profile under citrus production. Soil Sci. 165: 343-353.

Rendom, E. and A. Ambri. 1980. Response of tomato varieties to soil water tension during fruit development and ripening. PhD dissertation. University of California, Davis.

Rudich, J. and U. Luchinsky. 1994. Water economy. In: The Tomato Crop (eds. J.G. Atherton and J. Rudich) Chapman and Hall, pp. 335-367.

Steudle, E., U. Zimmermann and U. Luttge. 1977. Effect of turgor pressure and cell size on the wall elasticity of plant cells. Plant Physiol. 59: 285-289.

Thompson, T.L., T.A. Doergo and R.E. Godin. 2000. Nitrogen and water interactions in subsurface drip-irrigated cauliflower: 1. Plant response. Soil Sci. Soc. Am. J. 64: 406-441.

Tumbare, A.D., B.N. Shinde and S.U. Bhoite. 1999. Effect of liquid fertiliser through drip irrigation on growth and yield of okra (*Hibiscus esculentus*). Ind. J. Agron. 44: 196-178.

Yrisarry, J.J., M.H. Prieto Losada and A. Rodriguez del Rincon. 1993. Response of processing tomato to three different levels of water and nitrogen applications. Acta Hort. 335: 149-153.

Zapata, F. 1990. Isotope technique in soil fertility studies. In: Hardarson, G. (Ed.). Use of Nuclear Techniques in Studies of Soil-Plant Relationship. International Atomic Energy Agency, Training Course Series No. 2, pp 61-127.