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Estimating nitrogen nutritional crop requirements of grafted tomatoes under field conditions

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ABSTRACT

An experiment was conducted to test the hypothesis that the enhanced yield possible with grafted tomato (*Solanum lycopersicum* L.) under field conditions will also increase the nitrogen (N) crop nutritional requirement (CNR). Determinate 'Florida 47' tomatoes were grafted onto interspecific hybrid rootstocks ('Multifort' or 'Beaufort') and grown in a sandy soil with six N rates (56, 112, 168, 224, 280, and 336 kg ha^{-1}) under plastic mulched bed and drip-irrigation systems during the spring seasons of 2010 (March–June) and 2011 (April–July). The N-CNR for grafted and non-grafted tomatoes was assessed using five yield response functions: exponential, linear-plateau, quadratic-plateau, quadratic, and square root. Over the two seasons, the estimated N-CNR ranged from 165 kg ha^{-1} with the quadratic-plateau model to 324 kg ha^{-1} with the square root model. Confidence intervals (CI) around these N-CNR ranged from 125 to 585 kg ha^{-1} using the bootstrap method and from 98 to 440 kg ha^{-1} using the delta method. Analysis of these CIs gave N-CNR rates of 239–246 kg N ha^{-1} for grafted plants, and 196–197 kg N ha^{-1} for non-grafted plants. Predicted maximum marketable yields were similar between the models, ranging from 56 -71 Mg ha^{-1} for grafted plants, and 43–53 Mg ha^{-1} for non-grafted plants, over the two seasons. Overall, while the actual N-CNR is likely to vary with season, soil types, and management practices, the results indicated that grafted tomato plants had a greater N-CNR than non-grafted plants together with an increase in predicted marketable yield. The yield response curves also showed that at a fixed marketable yield goal within the estimated range, the N fertilization rate required was lower for the grafted tomato plants as compared with the non-grafted plants. This study demonstrated that N fertilization program for optimizing tomato production may be modified when grafted plants are used.

1. Introduction

The use of vigorous, interspecific hybrid rootstocks has shown enhanced growth and fruit yields for several solanaceous and cucurbitaceous vegetable crops, including tomato (*Solanum lycopersicum* L.), watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai), melon (*Cucumis melo* L.), cucumber (*Cucumis sativus* L.), pepper (*Capsicum annuum* L.) and eggplant (*S. melongena* L.) (Lee and Oda, 2003; Passam et al., 2005; Leonardi and Giuffrida, 2006; Colla et al., 2008, 2010; Di Gioia et al., 2010; Djidonou et al., 2013). For example, a 39% increase in total marketable yield of grafted versus non-grafted watermelon across three N rates (0, 50, and 100 kg ha^{-1}) was accompanied by a 21% relative increase in N uptake efficiency (Colla et al., 2011). However, yield potential for these grafted cucurbits at even higher N levels have not been examined. In tomatoes, increased N uptake has also been observed in grafted relative to non-grafted plants (Leonardi and Giuffrida, 2006). It is very likely that the N-CNR and recommended N fertilization rates may differ for grafted versus non-grafted tomatoes.

In general, the CNR represents the total, seasonal rate of N required by a given crop to achieve maximum yields (Cantliffe et al., 2006). Specifically in Florida, recommended N fertilization rates for field-grown tomato are based on empirical studies that assessed the CNR across various tomato growing areas (Cantliffe et al., 2006; Hochmuth and Hanlon, 2010). Results of these various studies have led to a recommended N rate of 224 kg ha^{-1} for field-grown, round, plum-type, and grape tomato production on sandy soils in Florida (Olson et al., 2009). On the other hand, empirical values of the

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CNR have been shown to vary depending on the tomato cultivars, planting seasons, soil, and irrigation systems (Scholberg et al., 2000; Simonne et al., 2008; Hochmuth and Hanlon, 2010; Ozores-Hampton et al., 2012). Therefore, given the increased growth, vigor, and yield commonly seen with grafted tomato plants, the N-CNR for grafted plants could possibly differ from that of non-grafted tomato, necessitating different fertilizer N recommendations than those currently in place.

Crop nutritional requirements for N are traditionally derived from field or greenhouse trials in which crop yield response to increasing N rates is measured. Several models are commonly used for estimating the N-rate corresponding to the CNR for a given crop. Tageldin and El-Gizawy (2005) summarized a number of the most frequently used models including, the linear-plateau, quadratic, quadratic-plateau, square root, and exponential models. Specifically, comparing five (quadratic, square root, linear-plateau, quadratic-plateau, and exponential) of these different models, Cerrato and Blackmer (1990) found that all models fit the data equally well based on the coefficient of determination (R^2), but concluded that the quadratic-plateau was the best to describe corn (*Zea mays* L.) yield response to N rates based on the residual analysis of each model. Furthermore, Willcutts et al. (1998) used the logistic, linear-plateau, and quadratic models, and found that the logistic model best described lettuce yield response to applied N. After the best model selection, the CNR, i.e., the optimum N rate is then estimated. Anderson and Nelson (1975) noted that CNR estimates often vary with the model selected. For example, although commonly used for describing crop response to N rates, the quadratic model tends to overestimate the response if the maximum point on a given curve is taken as the best fertilization rate, especially compared with other models such as linear-plateau or quadratic-plateau (Willcutts et al., 1998; Ozores-Hampton et al., 2012).

In practice, the N-CNR is often determined as a point estimate based on the best fit model without considering the statistical uncertainty associated with estimating the parameters in the model. Hernandez and Mulla (2008) stressed the need to account for the variability, which in general results from factors such as annual climate differences and within-field soil differences. They pointed out that confidence intervals (CIs) of the estimated optimum N rate should be evaluated and examined before making final N recommendations.

Several methods exist for determining the CI associated with the N-CNR including, the Wald-type CI, the profile-likelihood based CI, and the bootstrap CI (Hernandez and Mulla, 2008). Wald-type CIs are the traditional CI based on the asymptotic normality of the parameter estimates. In contrast, the bootstrap method is based on an approach that involves resampling the data in order to estimate the sampling distribution of the parameter estimates and derive CIs (Efron and Tibshirani, 1986). Hernandez and Mulla (2008) found that bootstrap methods present greater ability to quantify uncertainty in optimum N rates in comparison with the traditional Wald-type CI. This is because Wald-type method seems to overestimate the lower limit and underestimate the upper limit of the CI when compared to the bootstrap method. More recently, Jaynes (2011) used a Monte Carlo method to determine the expectation, confidence bands, and cumulative probability distributions for the economically optimal nitrogen rate (EONR) of corn (*Z. mays* L.) trials using different models. The author concluded that when EONR is estimated from yield data, both point estimates and a measure of its statistical reliability should be reported.

The goal of this study was to determine the N-CNR for drip-irrigated, grafted tomato under field conditions in sandy soils. Compared with previous studies, this study addressed the yield response of grafted tomatoes under a wider range of N rates from 56 to 336 kg ha^{-1}. This information is needed to provide updated tomato production recommendations given the increasing interest in tomato grafting among growers. Therefore, the objectives of this study were to: (1) compare the goodness of fit of five different models for marketable tomato fruit yield as a function of N rate, (2) estimate the N rates which maximize the marketable fruit yield in field production of grafted tomato for sandy soils in Florida, and (3) assess the uncertainty associated with these estimated N rates.

2. Materials and methods

2.1. Field experiment

The field studies of grafted and non-grafted tomato production were carried out at the University of Florida – Institute of Food and Agricultural Sciences (UF/IFAS) Suwannee Valley Agricultural Extension Center near Live Oak, FL (30.31° N, 82.90° W) during the spring growing seasons of 2010 and 2011. Tomato plants were grown in raised beds with plastic mulch and drip irrigation. The planting beds were 0.71 m wide and spaced 1.52 m apart with an in-row spacing of 0.46 m between plants. Grafted and non-grafted tomato plants were transplanted to the field plots on 29 March 2010 and 1 April 2011. A detailed description of the experimental setup can be found in Djidonou et al. (2013). A split-plot design with four replications (blocks) was used in both years. The whole plot treatments consisted of six N fertilization rates arranged in a randomized complete block design. The six total N rates were 56, 112, 168, 224 (UF/IFAS recommended rate), 280, and 336 kg ha^{-1}. Each of these included a preplant application of 56 kg ha^{-1}. Therefore, injected N rates were 0, 56, 112, 168, 224, and 280 kg ha^{-1} (Table 1). The subplot treatments included the determinate tomato cultivar 'Florida 47' (Seminis Vegetable Seeds, Inc., St. Louis, MO, USA) grafted onto 'Beaufort' (FL/BE) or 'Multifort' (FL/MU) rootstock (De Ruiter Seeds Inc., Bergschenhoek, The Netherlands) as well as the non-grafted 'Florida 47' (FL) as the control. Each experimental unit consisted of 12 plants. Irrigation was maintained at the current UF/IFAS recommendation for irrigation for field production of round tomato in sandy soils in Florida, i.e., 9354–37416 L/ha/day depending on the crop stage. After preplant fertilization, the remaining N fertilizer was injected weekly through the drip tape (John Deere Ro-Drip, San Marcos, CA, USA; 2.98 L/m/h at 82.74 kPa; 30.48-cm emitter spacing) based on the fertigation schedule recommended by Olson et al. (2009). Ammonium nitrate (34-0-0, Mayo Fertilizer Inc, Mayo, FL, USA) was used as the N source. Following soil test results, potassium chloride (Dyna Flo 0-0-15, Chemical Dynamics Inc., Plant City, FL, USA) was also used through fertigation to provide each treatment with amount of K needed (158 kg ha^{-1}) after accounting for the preplant application. Fruit were harvested 80 and 88 d after transplanting (DAT) in 2010, and 75, 85, and 92 DAT in 2011. Tomato fruit reaching the mature green stage or more advanced ripening stages were harvested from 10 plants in the center of each plot for estimating the marketable fruit yield (Mg ha^{-1}).

2.2. Marketable yield response functions

Historically, models that parametrically describe the expected yield ($E(Y)$) as a predetermined function of N (X) were used. Here, marketable yield was modeled as a function of N rate using five linear and nonlinear models commonly cited in horticultural literature, including: (1) quadratic, (2) square root, (3) linear-plateau, (4) quadratic-plateau, and (5) exponential models (Cerrato and Blackmer, 1990; Willcutts et al., 1998)

$$E(Y) = \beta_1 + \beta_2 X + \beta_3 X^2 + \varepsilon \quad (1)$$

$$E(Y) = \beta_1 + \beta_2 X + \beta_3 X^{1/2} + \varepsilon \quad (2)$$