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Fertilization and Catch Crop Strategies for Improving Tomato Production in North China

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ABSTRACT

Overuse of fertilizers and the resultant pollution and eutrophication of surface and groundwater is a growing issue in China. Consequently, improved management strategies are needed to optimize crop production with reduced nutrient inputs. Conventional fertilization (CF), reduced fertilization (RF), and reduced fertilization with maize (*Zea mays* L.) as a summer catch crop (RF+C) treatments were evaluated in 2008 and 2009 by quantifying tomato (*Lycopersicon esculentum*) fruit yield and soil nutrient balance in a greenhouse tomato double-cropping system. Fertilizer nitrogen (N) application was reduced by 37% in the RF and RF+C treatments compared to the CF treatment with no significant reduction in fruit yield. Mean soil mineral N (N_{min}) content to a depth of 180 cm following tomato and maize harvest was lower in the RF and RF+C treatments than in the CF treatment. Residual soil N_{min} content was reduced by 21% and 55% in the RF and RF+C treatments, respectively, compared to the CF treatment. Surplus phosphorus (P) and potassium (K) contents in the RF+C treatment were significantly lower than those in the RF treatment, mainly due to additional P and K uptake by the catch crop. We concluded that for intensive greenhouse production systems, the RF and RF+C treatments could maintain tomato fruit yield, reduce the potential for nitrate (NO_3^--N) leaching, and with a catch crop, provide additional benefits through increased biomass production.

Key Words: maize, nutrient surplus, nutrient uptake, reduced fertilization, soil mineral N, soil nutrient balance

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The total area of land devoted to vegetable production in China has exceeded 18.4 million ha over the last two decades and accounted for 11.6% of the total agricultural cropping area in 2009. Tomato (*Lycopersicon esculentum*) is the most widely grown vegetable, and is typically produced in poly-tunnel greenhouses occupying more than 60 000 ha (Ministry of Agriculture of the People's Republic of China, 2010). Conventional practices use frequent and excessive fertilization (especially nitrogen (N)) and irrigation to ensure maximum yields. For example, Chen *et al.* (2004) reported that greenhouse tomato crops in Beijing received more than 1 000 kg N ha^{-1} per growing season from manure and fertilizer applications, while He (2006) reported that between 1994 and 2004 the mean application rate per growing season was 2 227 kg N ha^{-1} for greenhouse tomato crops in Shouguang, Shandong Province. Such practices result in excessive root zone nutrient loadings, especially nitrate (NO_3^-) that can be easily lost due to the shallow rooting systems of some vegetable crops (Thorup-Kristensen, 2006; Verma *et al.*, 2007). Consequently, increased soil NO_3^- concentrations and subsequent leaching have degraded surface and groundwater quality (Zhang *et al.*, 2013).

Furthermore, during the wet summer season (July and August) in North China, the polyethylene film is typically removed from the greenhouses, leaving the soil fallow and thus allowing any mobile soil nutrients such as NO_3^- to be easily lost through leaching. The practice of 'reduced fertilization' considers the balance between crop N uptake and soil supply. For tomato crops, fertilizer N inputs can be reduced by 70% with a subsequent reduction in soil N loss of 54% (Ren *et al.*, 2010), while for cucumber (*Cucumis sativus* L.) crops, reducing fertilizer N by 53% has reduced soil N losses by 45% (Guo *et al.*, 2008). Although reduced fertilization strategies consider the N supply during the crop growing season, to date, they have not considered residual soil N or the N released by mineralization during fallow periods to be vulnerable to leaching.

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Catch crops are quick-growing plants sown during fallow periods between main crops to reduce NO_3^- leaching (Sainju and Singh, 1997). Nitrate leaching has been reported to decrease by 29%–94% in systems with non-leguminous catch crops (a mean reduction of 70% reported by Tonitto *et al.*, 2006) and by –6%–48% with leguminous catch crops, when compared with bare fallow systems (Sainju and Singh, 1997). The potential impact of catch crops for reducing NO_3^- leaching is sufficient that some countries, *e.g.*, Denmark (Munkholm and Hansen, 2012), have now adopted them as key elements in their national N management strategies. Plant species with deep rooting systems, rapid biomass accumulation and high nutrient uptake capacity (especially C4 plant species) are particularly efficient as summer catch crops (Snapp *et al.*, 2005; Wang *et al.*, 2005). Ju *et al.* (2007) also demonstrated the high risk of NO_3^- leaching in the summer season in China and suggested that deep-rooted species such as maize could be used as a catch crop to intercept soil NO_3^- deep in the soil profile and consequently reduce NO_3^- leaching. Catch crops can also deliver other benefits such as increased soil organic matter content, resulting in carbon sequestration services and improved soil quality, as well as providing additional productivity from land which would otherwise be left fallow. This can take the form of bioenergy crops, animal fodder (Munkholm and Hansen, 2012), green manures (Sorensen and Thorup-Kristensen, 2011), and despite the short growing season, even food for human consumption (*e.g.*, baby sweet corn in the case of maize).

While the potential benefits of catch crops are becoming more widely recognized, research is still required into their application in different systems and optimization under different fertilizer regimes, cropping systems and soil types. The combined effects of reduced fertilization and growing of catch crops have not been studied for tomato cropping systems in North China. We hypothesize that a combination of catch crops and reduced fertilization strategies can reduce the potential for nutrient leaching while maintaining productivity of greenhouse tomato systems in this area. To test this, tomato plants were grown in greenhouses for four growing seasons using three different cropping systems: conventional fertilization, reduced fertilization, and reduced fertilization with the inclusion of a catch crop (maize) during fallow periods.

MATERIALS AND METHODS

Experiments

Continuous double-crop tomato experiments were carried out in greenhouse poly-tunnel systems over four growing periods (winter-spring (WS) from February to June and autumn-winter (AW) from September to January from 2008 to 2009 in Changping (40°10′56.36″ N, 116°15′52.52″ E), Beijing, China. After the June harvest, the greenhouse covering was removed, leaving the soil open to the atmosphere during the fallow period (July–August). The soil was a fluvo-aquic soil containing 760, 230, and 10 g kg^{-1} sand, silt and clay, respectively. Its chemical properties were: pH (H_2O), 7.2; total N, 2.2 g kg^{-1}; Olsen-P, 97 mg kg^{-1}; NH_4OAc-extractable K, 210 mg kg^{-1}; organic matter, 21.2 g kg^{-1} (Jiang, 2009).

Conventional fertilization (CF), reduced fertilization (RF), and reduced fertilization with maize as a summer catch crop (RF+C) treatments were evaluated using a randomized block design with three replicates of 6 m × 4 m plots. Four-week-old tomato (Xianke 1) seedlings were transplanted into the greenhouses in February (WS season) and September (AW season) each year. Fruit harvest commenced in May and November and ended in June and January. For the catch crop treatment, three-leaf maize (Tianzi 22) seedlings were transplanted at a spacing of 60 cm × 30 cm at the end of June and harvested in September.

Chemical NPK fertilizers were surface applied during each growing period (Table I). The amount of chemical fertilizers for the CF treatment are according to the conventional practice in this area, and those for the RF and RF+C treatments based on the determination of soil nutrient status. A blended fertilizer was used in 2008 (N:P:K ratio of 2.38:1:3.38), while in 2009, urea (46% (w/w) N), calcium monophosphate (12% (w/w) P_2O_5) and potassium sulfate (50% (w/w) K_2O) were applied separately for each treatment. A uniform application of chicken manure (16.7, 20, and 30 t ha^{-1} for the CF, RF, and RF+C treatments, respectively) was also applied to each treatment at the start of each growing season. Table II shows the amounts of N, P, and K applied *via* the manure.

Total weekly water application *via* drip irrigation was 159 and 116 mm in 2008 and 185 and 151 mm in 2009 in the WS and AW seasons, respectively. The greenhouse was covered with polyethylene film except from August 9 to September 6 each year. Precipitation during those periods was 55.5 and 74.2 mm in 2008 and 2009, respectively. Except for an initial 35 mm of irrigation at planting, no additional fertilizer or irrigation was applied to the maize crop.

Plant and soil sampling and measurements

Immediately before planting and after harvest of tomato and maize plants, three soil cores were collected from each plot. Three rows of plants were selected