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Responses of soil properties, crop yield and root growth to improved irrigation and N fertilization, soil tillage and compost addition in a pepper crop

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ABSTRACT

Two improved management packages of tillage, irrigation, and nitrogen (N) management were compared with conventional management (CM), in a sweet pepper crop, in a plastic greenhouse in southeastern Spain. Crops were grown in a layered "enarenado" soil. The two improved packages included prescriptive and corrective irrigation management using, respectively, the PrHo program and tensiometers, and prescriptive N management using the VegSyst-DSS program. In both improved packages, soil was tilled to 10 cm prior to transplanting after temporarily removing the sand mulch layer. In one of the improved packages, the "reduced input and tillage plus compost" (RIT + C), compost was incorporated during tillage. In the other improved package, the "reduced input and tillage" (RIT), no compost was added; otherwise, management was identical in both improved packages. Total volumes of applied irrigation and of drainage, and the total amounts of applied N were reduced in RIT and RIT + C compared to CM. However, the RIT and RIT + C packages were associated with slightly less fruit production than CM. This was attributed to higher root zone salinity and an apparent slight N deficiency. Biomass, fruit production and root growth were lowest in RIT + C, which were attributed to salts added in the compost. Relative to the untilled CM soil, soil tillage in the RIT package reduced soil bulk density and favoured deeper root growth. Compared to RIT, compost addition in RIT + C was associated with less root growth presumably because of higher salinity. To optimize N management, the use of N monitoring during the crop (i.e. corrective management of N) is required when prescriptive N management is being used. Long term practices of tillage and organic matter addition may be required to appreciably improve soil quality in this agricultural system. Care may have to be taken to ensure that excessive quantities of salts are not added when applying compost.

1. Introduction

Protected cultivation of horticultural crops in Mediterranean plastic greenhouses, with low to medium levels of technology, is common throughout the Mediterranean Basin, where there are approximately 200,000 ha of these greenhouses (Pardossi et al., 2004). The largest concentration is in the coastal region of southeastern (SE) Spain (Castilla and Hernández, 2005). In this region, approximately 38,000 ha of relatively simple plastic greenhouses are used for intensive vegetable production; the majority of these greenhouses are concentrated in the province of Almeria (Junta de Andalucia, 2013). Approximately 90% of the greenhouse area in the province of Almeria is cropped in soil (García García et al., 2016).

Intensive vegetable production systems are generally characterized by large applications of mineral nitrogen (N) fertilizer (Neeteson, 1994; Ramos et al., 2002; Thompson et al., 2007c). Commonly, the N supply considerably exceeds crop N requirements (Ju et al., 2006; Soto et al., 2015) resulting in nitrate (NO_3^-) leaching loss (Gallardo et al., 2006; Zotarelli et al., 2007). The intensive horticultural system of SE Spain is prone to NO_3^- leaching loss (Thompson et al., 2007c), which is associated with substantial contamination of underlying aquifers (Pulido-Bosch et al., 2000; Thompson et al., 2007c). The areas where

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greenhouses are concentrated in Almeria have been declared nitrate vulnerable zones (Junta de Andalucía, 2008), in accordance with the European Union Nitrate Directive (Council of the European Communities, 1991), and consequently, there is a requirement to reduce NO_3^- leaching losses. This will require improved management of both nitrogen (N) and irrigation (Thompson et al., 2017).

In intensive vegetable production systems with combined drip irrigation and fertigation systems, N is commonly applied frequently and in small amounts throughout the whole crop cycle (Granados et al., 2013; Hartz and Hochmuth, 1996; Sonneveld and Voogt, 2009; Thompson et al., 2017). Because of the widespread use of automatically-controlled combined drip irrigation and fertigation systems, greenhouses in Almeria have the technical capacity to “spoon-feed” both N and water to match crop demand. However, these vegetable growers lack the management tools to take advantage of this advanced technical capacity. Current grower practice is to use standard programs or recipes for both N and irrigation (Thompson et al., 2007c), in which the amounts of N and irrigation applied are fixed. Although these standard programs or recipes ensure high levels of production, they also result in excessive N and irrigation application.

Several approaches have been developed in recent years to improve the management of both N and water for soil-grown vegetable crops in the Almeria greenhouse system. Fernández et al. (2009) developed the irrigation computer program PrHo v2.0 (Cajamar Foundation) that calculates irrigation requirements of greenhouse-grown vegetable crops based on modelling crop evapotranspiration (ETc) following the FAO methodology (Allen et al., 1998). The VegSyst decision support system (VegSyst-DSS), based on the VegSyst crop simulation model (Giménez et al., 2013), has been developed to calculate daily crop N requirements of greenhouse-grown vegetable crops in Almeria (Gallardo et al., 2014). The VegSyst-DSS calculates daily N fertilizer requirements based on daily crop N uptake after considering N supplied from soil sources. Recently, the VegSyst-DSS was calibrated for all of the major vegetable crop species grown in greenhouses in Almeria (Gallardo et al., 2016b) and the Windows-based VegSyst-DSS software (http://www.ual.es/GruposInv/nitrogeno/VegSyst-DSS.shtml) has been developed for use by technical advisors (Gallardo et al., 2016a,b). There has also been appreciable work, conducted in this system, evaluating soil moisture sensors for irrigation management (Gallardo et al., 2013; Thompson et al., 2007a,b). Of the various soil moisture sensors examined, tensiometers for measurement of soil matric potential have been recommended as being the most suitable for greenhouse-grown vegetable crops on account of their simplicity, low cost, direct measurement, adequate working range, ease of use, and the relative simplicity of irrigation decision making based on soil matric potential (Gallardo et al., 2013).

Soil compaction is a major problem facing modern agriculture. Intensive cropping cycles, inadequate soil management and frequent short season crops contribute to compaction, which is exacerbated by low soil organic matter content and high moisture content (Hamza and Anderson, 2005). Compaction impedes root penetration (Batey, 2009; Kadžienž et al., 2011), reducing root proliferation throughout the soil (Abu-Hamdeh, 2003; Tracy et al., 2013) and restricting root development to the upper part of the soil profile (Guaman et al., 2016; Passioura, 1991). These effects limit the root systeḿs capacity to absorb water and nutrients which can affect crop growth and yield (Batey, 2009; Erdem et al., 2006; Iler and Stevenson, 1991; White et al., 2015). A reduced capacity to absorb available nutrients, from the deeper zones of the soil profile, will increase the likelihood of NO_3^- leaching loss (Thorup-Kristensen, 2011). By enabling deeper rooting, tillage will likely contribute to more efficient use of N and water (Thorup-Kristensen, 2011).

There is the notion among farmers and technical advisors that appreciable soil compaction occurs in greenhouse-grown vegetable crops in Almeria, as a result of the continuous movement of farm workers on the surface of the continually-moist soil (López-Gálvez and Naredo, 1996). All management activities such as transplanting, pruning, harvesting, tying guide cords to crops, and application of pest protection products are conducted manually. The complete lack of regular soil tillage enhances soil compaction and modifies root development leading to shallow rooting (Castilla, 1986). Studies with tomato and sweet pepper have shown that root systems are restricted to several centimetres of the upper part of soil profile (Castilla et al., 1986; Martínez Raya, 1987). Tillage of greenhouse soils reduced bulk density and led to higher root density in the cultivated and deeper soil layers in tomato and sweet pepper crops in Almeria (Castilla, 1986; Martínez Raya, 1987). Tillage to 125 mm with mouldboard plough improved root and crop development of greenhouse-grown pepper in Turkey (Erdem et al., 2007), and tillage increased yield in open-field cucumber in North Carolina, USA (Osmond et al., 2011). The addition of organic material may enhance the effects and duration of tillage (Hamza and Anderson, 2005). Organic amendments have been shown to improve soil physical characteristics and nutrient retention in greenhouse soils (Hamza and Anderson, 2005; Scotti et al., 2016; Willekens et al., 2014).

Improved management to reduce NO_3^- leaching in the greenhouse-based vegetable production system of SE Spain will require improved management packages that combine both N and irrigation management. By reducing soil bulk density and increasing porosity and aeration, tillage may enable deeper root penetration and enhance the effectiveness of improved N and irrigation practices. Compost addition may further enhance and prolong the effects of tillage.

The objective of the present work was to examine the effects of three different crop management packages on soil properties, crop yield and root growth of pepper grown under greenhouse conditions. The packages were: (1) conventional management of N fertilization and irrigation, both based on local recipes with no soil tillage, (2) improved irrigation and N management by use of the PrHo and VegSyst-DSS programs, tensiometers and soil tillage, and (3) the same management described in package (2) with the addition of compost. The effectiveness of the management packages was evaluated by comparing the amounts of applied N and irrigation, drainage, crop dry matter production and yield, and root length density in different soil depths.

2. Material and methods

2.1. Location and cropping details

The experimental work was conducted in the research station of the Cajamar Foundation, located in El Ejido, Almeria, SE Spain (36° 48′ N, 2° 43′ W and 151 m elevation). A sweet pepper (*Capsicum annuum* ‘Ebro’) crop was grown in soil in two identical, plastic greenhouses very similar to those used for commercial intensive vegetable production system in SE Spain. The two greenhouses were adjacent to one another along their east–west orientation and have had very similar cropping histories. Each greenhouse was 24 m long by 18 m wide; they were unheated and passively ventilated. The greenhouse cladding was low density polyethylene (LDPE) tri-laminated film (200 μm thickness).

Three packages of crop management were applied. In one greenhouse, conventional management (CM) of N and irrigation was used. In the other greenhouse, two management packages were applied, a reduced input and soil tillage management (RIT) package and a reduced input and soil tillage plus addition of compost (RIT + C) package. There were four plots of each management package; each plot measured 12 (l) × 8 (w) m in the greenhouse of the CM, and 12 (l) × 4 (w) m in the greenhouse of the RIT and RIT + C packages. There were border areas along the edges of the greenhouse. Each greenhouse was divided into northern and southern halves by a 1.5 m wide concrete path with an east–west alignment. In the RIT and RIT + C packages, two plots of each package were in each of the northern and southern halves.

The crop was grown in an artificial layered “enarenado” soil typical of the region (Bretones, 2003), consisting of a 30 cm layer of silty clay