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Aromatic plants as soil amendments: Effects of spearmint and sage on soil properties, growth and physiology of tomato seedlings

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ABSTRACT

Improvement of soil characteristics through the use of renewable inputs is fundamental to environmentally friendly farming systems. In the present study, the potential of improving soil properties and, consequently, growth of tomato (*Lycopersicon esculentum* L.) seedlings through a direct incorporation of aromatic plant tissues into seedbeds is assessed. Dried spearmint (*Mentha spicata* L.) and sage (*Salvia fruticosa* Mill.) tissues are incorporated at different rates into the soil of experimental field plots. At 0, 20, 40, 60, and 90 days following incorporation, soil samples are removed from the plots and used as substrates in tomato seedbeds. Growth and physiological parameters of tomato seedlings (emergence, size of the most robust leaf, shoot length, dry weight, net photosynthetic rate, stomatal conductance, photosynthetic yield) as well as soil attributes (pH, nitrogen and organic carbon content, organic matter decomposition rate, microbial populations, changes in essential oil content) are monitored. Spearmint incorporation into the soil improved emergence, physiology and growth of tomato seedlings. This was not the case with sage. Soil microbial populations and organic matter decomposition increased with increasing rate of incorporated aromatic plant tissues, especially in the case of spearmint which exhibited a more prominent increasing trend. Soil pH was not affected, remaining within the range for optimum tomato growth. Further, C:N ratio increased, yet it did not inhibit tomato growth. Lastly, the observed decrease with time of the essential oil content in soil was dependent on the aromatic plant incorporated, and is discussed in relation to the beneficial effects of spearmint on tomato growth. The herein undertaken study demonstrates that incorporating intact spearmint tissues into the soil is a promising tool for improving tomato seedling production. This practice circumvents the arduous composting process and, therefore, it can be more cost-and-time-effective compared to the currently applied techniques.

1. Introduction

Soil amendments aim to improve soil properties. This includes increase of the soil organic matter and of the nutrient pool, stimulation of beneficial microbial populations and/or suppression of pathogens and weeds. The desired outcome of all these beneficial effects is the improvement of soil fertility and consequently of its productivity. Soil amendments are of particular importance in organic farming; most often, they are composted organic materials of different origin.

The biological process of composting is the most commonly used method for the fermentation of organic materials prior to their incorporation into the soil. The key element of this process is the production of a stable and mature end product suitable for use as soil amendment. In general, the composted organic material positively affects important soil features and processes, and has beneficial impacts on the environment surrounding agricultural systems (Hargreaves et al.,

Abbreviations: DAE, days after establishment of the field experiment (i.e. days after incorporating aromatic plant tissue into the soil, coinciding with the sampling times); CFU, colony forming units.

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2008; Toumpeli et al., 2013). In particular, activity, diversity, and structure of soil microbial communities have been shown to respond fast to such agricultural management practices. Hence, they can provide insight into the impact of management on soil quality (Arancon et al., 2003; Diacono and Montemurro, 2010).

There is a plethora of composted materials that can be used as soil amendments in agricultural systems. So far the primary materials used for composts have been municipal and agricultural wastes. This practice is attributed to the environmental benefits associated with the use of such materials contributing to pollution reduction and nutrient recycling, besides maintaining soil fertility (Hargreaves et al., 2008; Snyman and Vorster, 2011; Tella et al., 2013). Consequently, the use of alternative sources for compost, such as naturally occurring or cultivated aromatic plants, has received relatively limited attention thus far (Chalkos et al., 2010; Dhima et al., 2009).

However, there is important scope in examining aromatic plants as potential soil amendment due to their abundance in the Mediterranean cultivated and natural ecosystem and due to their multifaceted biological activity. In particular, their essential oils have been shown to selectively affect various organisms inducing both stimulatory and inhibitory effects on weed germination and growth (Angelini et al., 2003; Dudai et al., 1999; Vasilakoglou et al., 2007), inhibiting several plant pathogens (Daferera et al., 2003; Kadoglidou et al., 2011; Karamanoli et al., 2000), and enhancing soil metabolism and microbial activity (Broudiscou et al., 2007; Owen et al., 2007; Vokou and Liotiri, 1999; Vokou et al., 2002). Use of these plants and of their metabolites in agriculture could have many advantages because of their (i) natural origin, making them less harmful than synthetic chemicals, (ii) volatility, implying less residue on the produce or in the environment after application, and (iii) composite nature, implying multiple mechanisms of action that prevent pathogens from developing resistance to all participating compounds (Chalkos et al., 2010). Nevertheless, we are dealing with costly materials, therefore this practice might be advisable only in small scale applications, e.g. in seedbeds for production of profitable vegetables or ornamental crops.

In this respect, the authors previously assessed (Chalkos et al., 2010) the potential of using composts derived from spearmint and sage as soil amendments in tomato cultivation. To this end, this paper considers the incorporation of intact (above grown dry biomass) material from aromatic plants directly to the soil, that is, with no prior composting, to improve productivity in tomato (*Lycopersicon esculentum* L.) seedlings. In this manner, the soil amendment practice becomes easier, faster and more cost-effective. To this aim, dried spearmint (*Mentha spicata* L.) and sage (*Salvia fruticosa* Mill.) tissues are considered for the purpose and their effectiveness is gauged by monitoring a comprehensive list of plant and soil parameters. It is noted that the choice of tomato as a case-study has been motivated by the fact that it is among the ten most important crops in South Eastern Europe (FAO, 2012) and by the fact that it is often used in rotations (Poudel et al., 2001) and, therefore, it holds an important role in alternative farming systems. Our interest was focused on tomato seedbed management, specifically on the requirement of producing healthy and rapidly growing seedlings in nurseries. It is estimated that a reduction of the transplanting period by only 3–5 days provides surplus benefit on the income of the tomato seedling suppliers. In addition, growers aim at producing robust seedlings as early in the growing season as possible, so as to minimize infections and subsequently maintain productivity in the greenhouse. Therefore, any manipulation that might satisfy the above requirements is of outmost importance.

2. Materials and methods

2.1. Plant material

The aromatic plants used in this study are the same as the ones used by Chalkos et al. (2010) in the form of composts, i.e. spearmint and sage. The two species differ in both their habit and essential oil. Spearmint is a herbaceous perennial species, whereas sage is a shrub. They both grow abundantly in the wild and are also cultivated in Greece. Spearmint, in particular, is the commonest mint species in the country forming large populations at an altitude between sea level and 1500 m (occasionally up to 2000 m) (Kokkini and Vokou, 1989).

The plant tissues applied here are the whole aboveground biomass, for spearmint, and the upper part of shoots, for sage. These were purchased from a commercial supplier. Plant tissues were cut into small pieces, air-dried in the dark till moisture content was approximately 5–7%, and stored in a cool (12 °C), dark and dry place until use. Storage duration varied from a few days to a few months, given that the whole experiment had to be repeated in time.

To estimate the essential oil content of the two aromatic plants, a quantity of the plant material purchased was water-distilled when dry (100 g each time) for 3 h in a Clevenger apparatus. The essential oils thus extracted from each species were analyzed by gas chromatography as described by Vokou et al. (1993) and by GC–MS as described by Karamanoli et al. (2008). The major constituents of these essential oils were identified on the basis of the retention times and according to the chemical profiles found by Karousou et al. (1998) and Kokkini and Vokou (1989). The essential oil yield of spearmint was 1.6 ml 100 g^{-1} d.w., that of sage 1.5 ml 100 g^{-1} d.w. Carvone (>50%) and 1,8-cineol (>40%) were the major constituents of the essential oils of spearmint and sage, respectively.

The above aromatic plants were applied as soil amendments in tomato seedbeds. Seeds (84% germination) of Carla F1 hybrid tomato (*Lycopersicon esculentum* L.) were used in the experiments.

2.2. Experimental design, methods and conditions

A field experiment was established at the farm of the Aristotle University of Thessaloniki (40° 32′ 08.74″N and 22° 59′17.76″E). The soil consisted of 32% clay, 56% silt, 12% sand, 1.5% organic matter and 7.5% $CaCO_3$ (analysis performed at the Soil Science Institute of the National Agricultural Research Foundation, Thessaloniki). Soil cation exchange capacity was 28.6 meq 100 g^{-1}. The experimental field, left in fallow for a 10-year period, was subdivided into 24 plots, 50 × 50 cm in size, separated from each other by a 50 cm wide alley. The top soil (upper 15 cm) from each plot was removed, weighed and mixed with plant material of either spearmint or sage, at rates of 0, 2, 4 and 8% (w/w, plant material:soil). Following this, the soil–aromatic plant mixture was put back to the plots (15 cm depth), at the bottom of which a plastic mesh had been placed. The mesh served in avoiding both an uneven incorporation of the mixture into the remaining soil, and a removal of samples from deeper untreated soil layers. The experimental field area was weekly irrigated and left without any further intervention. The examined soil treatments along with their abbreviations are shown in Table 1. A 2 × 4 (two types of plant material × four rates) factorial experiment was used in a randomized complete block design with three replications (plots) per treatment. The entire field experiment was repeated in time.

At 0, 20, 40, 60 and 90 days after the establishment of the field experiment (DAE), i.e. the replacement of the top soil by the soil–aromatic plant mixture (hence, the initiation of the decomposition process of the plant material), soil samples from each treated