Leonardite and Fertilizer Levels Influence Tomato Seedling Growth

A.J. Pertuit, Jr.¹, Jerry B. Dudley², and Joe E. Toler³
Clemson University, Clemson, SC 29634-0375

Abstract. New Mexico–mined raw leonardite was characterized by comparing it with the International Humic Substances Society’s Standard Leonardite. In the first experiment, adding as little as 1/64 leonardite (v/v) to a sand medium increased tomato [Lycoopersicon esculentum (L.) Mill. ‘Mountain Pride’] root and shoot growth compared with plants produced with fertilizer alone. Growth increased linearly with increasing leonardite levels, from 0% to 25%; however, 50% leonardite inhibited growth. In a second experiment, leonardite alone had no effect on plant height, shoot or root fresh and dry weight, or total leaf area, but stimulated growth when combined with a complete fertilizer. Adding 1/3 leonardite (v/v) (the highest level) and a complete fertilizer increased plant height 40%, total leaf area 160%, shoot fresh weight 134%, root fresh weight 82%, shoot dry weight 133%, and root dry weight 400%.

Leonardite is a naturally occurring, brown-black, oxidized form of lignite coal (O’Donnel, 1973). Humic substances are a primary constituent of leonardite and can be classified into humic acid, fulvic acid, and humin depending upon their solubility in alkali and acid (Schnitzer and Khan, 1972). With adequate mineral nutrition, humic substances can promote the growth of ‘Chardonnay’ grapevines (Vitis vinifera L.) (Reynolds et al., 1995), cucumber plants (Cucumis sativus L.) (Rauthan and Schnitzer, 1981), corn plants (Zea mays L.) (Tan and Nopamornbodi, 1979), and tomatos (Bryan, 1976). These positive effects of humic substances are often correlated with enhanced macronutrient uptake, as well as their ability to complex transition metals such as Cu, Zn, Fe, and Mn (Chen and Aviad, 1990). In contrast, excessive concentrations of humic substances can inhibit growth (Ayuso et al., 1996; Bryan, 1976; Rauthan and Schnitzer, 1981; Reynolds et al., 1995). These inhibitory effects have been correlated with the presence of excessive ligands, which reduce micronutrient availability to plant roots (Ayuso et al., 1996; Rauthan and Schnitzer, 1981).

Leonardite characterization. To characterize the Leonardite material employed in these tests, a sample of the IHSS Standard Leonardite was obtained and analyzed along with our New Mexico leonardite (Humate Resources, Edina, Minn.). To determine moisture content, a sample was weighed at room temperature, oven-dried at 105 °C for 24 h, then weighed. Cation exchange capacity (CEC) was determined by the sum of cations [CEC_{\text{sum of cations}} = \Sigma \text{exchangeable bases (Ca, Mg, K, Na)} + \text{extractable acidity}]. Exchangeable bases were determined via the ammonium acetate method, and extractable acidity was measured using the barium chloride-triethanolamine method (Thomas, 1982). Total organic carbon (TOC) was determined using a Shimadzu TOC-5000 with SSM-5000 solid sample analyzer (Shimadzu Corp., Kyoto, Japan). The value obtained was multiplied by a factor of 1.724 to determine total organic matter (Schnitzer, personal communication). Humic and fulvic acids were extracted using 0.1 M NaOH and separated using 6 M HCl (Schnitzer, 1982). The TOC of each fraction was determined using a Shimadzu TOC-5000 (Shimadzu Corp.). The humic acid TOC was multiplied by a factor of 1.724 to determine total humic acid, and the fulvic acid TOC by a factor of 2.0 to determine total fulvic acid (Schnitzer, personal communication). Total N was released from the leonardite sample by high temperature combustion under high-purity oxygen and quantified by thermal conductivity detection (Association of Official Analytical Chemists, 1994a). Extractable P and K were determined by extraction from leonardite with ammonium citrate (pH 7.0) in the presence of disodium ethylenedinitrilotetraacetic acid (EDTA) (Association of Official Analytical Chemists, 1994b), and analyzed using inductively coupled plasma emission spectrometry (ICP). Total Fe, Mg, Ca, S, Mn, Cu, Zn content were determined by digestion of leonardite samples with HNO₃, and H₂O₂ (Association of Official Analytical Chemists, 1990b), and then analyzed using ICP. Acid-extractable B content was determined using the spectrophotometric method (Association of Official Analytical Chemists, 1990a).

The amount of water-extractable fulvic acid was measured by placing 10 g of leonardite in 50 mL of distilled water. Each sample (three replicates for each day) was mechanically shaken for 1 h and filtered (0.45 µm pore size) after either 2, 4, 8, 16, or 32 d in solution. Each water extract was treated with 6 M HCl to precipitate any humic acid (Schnitzer, 1982). Total fulvic acid was determined as previously mentioned. Results were analyzed using regression analysis.

Procedure. Two experiments were conducted to evaluate the vegetative growth responses obtained by the addition of raw leonardite and/or fertilizer to the coarse sand (Play Sand, Quikrete Companies, Atlanta) growing medium. ‘Mountain Pride’ tomato seedlings were grown in 2.08-L pots in a greenhouse (15.5 °C minimum temperature). Two paper coffee filters were placed in the bottom of each pot to prevent the growing medium from washing through the bottom holes. Water was applied until it leached through the bottom holes, and the frequency of watering was the same for all treatments. The recommended rate of N application to field tomatoes is 140–168 kg ha⁻¹ (Cook, n.d.); therefore, if applied, 5 g of granular fertilizer (5N–4.3P–8.3K) was mixed throughout the growing.
ing medium in each pot. The Leonardite employed in these tests was from a New Mexico mine (Humate Resources, Edina, Minn.), and its texture was similar to that of laundry detergent.

**Expt. 1.** The first experiment was conducted to examine the effects of Leonardite on growth and to provide information about potential optimal and toxic levels. Twelve plants per treatment were arranged in a randomized complete-block design with three blocks. Seeds were sown in a peat-based germination medium 18 Feb., and transplanted (treatments applied) on 8 Apr. The media used are listed in Table 4. Data were recorded at harvest (14 May), when the first fruit began to develop (some up to 1.8 cm in diameter).

**Expt. 2.** Expt. 1 revealed that Leonardite at 1/2 volume was toxic and best results were obtained at 1/4 volume Leonardite; therefore, Expt. 2 was conducted with 1/3 volume Leonardite to confirm the results of Expt. 1. In this test, six plants per treatment were arranged in a randomized complete-block design with two blocks. Seeds were sown in a peat-based germination medium 29 July and transplanted (treatments applied) on 31 Aug. Treatments are listed in Table 5. Data were recorded at harvest on 7 Oct., when the first fruit began to develop.

**Statistical analysis.** Analysis of variance (ANOVA) was performed on the results from the experiments, and single degree-of-freedom contrasts were used to examine specific comparisons among treatment means and to evaluate polynomial relationships between plant responses and Leonardite levels at $P = 0.05$.

**Results and Discussion**

Physical and chemical properties and nutrient analysis of the New Mexico-mined Leonardite were compared with those of the IHSS Standard Leonardite (Tables 1 and 2). Laboratory tests revealed that water-soluble fulvic acids were released from Leonardite (Humate Resources, Edina, Minn.) after 2, 4, 8, 16, and 32 d in solution. The first experiment established the levels of Leonardite that enhance tomato growth (1/64 to 1/4 volume), as well as the toxic level (1/2 volume).

**Expt. 2.** The addition of Leonardite alone (no fertilizer) did not stimulate, and actually reduced, root fresh weight (Table 5). Leonardite alone increased both plant height and root fresh weight. When both Leonardite and fertilizer were added, linear increases were observed in plant height, total leaf area, shoot and root fresh weight, and shoot and root dry weight as the concentration of Leonardite increased. Additions of 1/3 Leonardite (the highest level) plus fertilizer increased plant height 40%, total leaf area 160%, shoot fresh weight 134%, root fresh weight 82%, shoot dry weight 133%, and root dry weight 400%. These results confirm those of other researchers (Ayuso et al., 1996).

| Nutrient (%)               | N  | P  | K⁺ | Fe | Mg | Ca | S  | B⁺ | Mn | Cu | Zn |
|----------------------------|----|----|----|----|----|----|----|----|----|----|----|
| Standard                   | 1.11 | 0.004 | 0.02 | 0.476 | 0.36 | 1.675 | 0.97 | 0.13 | 0.006 | <0.002 | 0.0011 |
| New Mexico                 | 1.30 | 0.008 | ND  | 2.151 | 0.13 | 0.795 | 1.48 | 0.009 | 0.003 | <0.002 | 0.0009 |

*Ammonium citrate-extractable in the presence of EDTA.  
*Acid-extractable.

| Inorganic nutrient (%)       | N  | P  | K⁺ | Fe | Mg | Ca | S  | B⁺ | Mn | Cu | Zn |
|------------------------------|----|----|----|----|----|----|----|----|----|----|----|
| Standard                     | 1.11 | 0.004 | 0.02 | 0.476 | 0.36 | 1.675 | 0.97 | 0.13 | 0.006 | <0.002 | 0.0011 |
| New Mexico                   | 1.30 | 0.008 | ND  | 2.151 | 0.13 | 0.795 | 1.48 | 0.009 | 0.003 | <0.002 | 0.0009 |

*Ammonium citrate-extractable in the presence of EDTA.  
*Acid-extractable.

**Table 2. Nutrient analysis of International Humic Substances Society (IHSS) Standard Leonardite [bulk source Gascoyne Leonardite (Gascoyne, N. Dak.) obtained from the IHSS] and New Mexico-mined Leonardite (Humate Resources, Edina, Minn.).**

| Time in solution (d) | 2 | 4 | 8 | 16 | 32 | Linear regression |
|----------------------|---|---|---|----|----|------------------|
| Standard             | 3.108 | 3.451 | 3.187 | 3.254 | 3.435 | ns |
| New Mexico           | 0.520 | 0.510 | 0.543 | 0.565 | 0.572 | * |

*ns: Nonsignificant or significant at $P < 0.05$, respectively.

**Table 3. Amount (mg) of water-extractable fulvic acid derived from one g of International Humic Substances Society (IHSS) Standard Leonardite [bulk source Gascoyne Leonardite (Gascoyne, N. Dak.) obtained from the IHSS] and New Mexico-mined Leonardite (Humate Resources, Edina, Minn.) after 2, 4, 8, 16, and 32 d in solution.**

| Fertilizer Leonardite (v/v) | Shoot | Root |
|-----------------------------|-------|------|
| None | None | 2.41 | 1.04 |
| +   |    | 4.63 | 1.50 |
| +   | 1/64| 4.85 | 2.04 |
| +   | 1/32| 4.99 | 2.02 |
| +   | 1/16| 4.50 | 2.05 |
| +   | 1/8 | 5.39 | 2.43 |
| +   | 1/4 | 5.72 | 2.80 |
| +   | 1/2 | 1.78 | 0.53 |

**Table 4. The effects of addition of Leonardite and/or fertilizer (5 g 5N–4.3P–8.3K/2.08-L pot) to a coarse sand growing medium on the shoot and root dry weights of tomato seedlings (Expt. 1).**
Table 5. The effects of addition of leonardite and/or fertilizer (5 g 5N–4.3P–8.3K/2.08-L pot) to a coarse sand growing medium on height, total leaf area, shoot and root fresh weights, and shoot and root dry weights of tomato seedlings (Expt. 2).

| Fertilizer | Leonardite (v/v) | Height (cm) | Total leaf area (cm²) | Fresh wt (g) | Dry wt (g) |
|------------|-----------------|-------------|----------------------|--------------|------------|
|            |                 | Shoot       | Root                 | Shoot        | Root       |
| None       | None            | 25.2        | 51.35                | 2.88         | 3.52       | 0.50      | 0.22     |
| None       | 1/4             | 29.8        | 92.28                | 4.85         | 4.15       | 0.80      | 0.30     |
| +          | None            | 38.8        | 242.87               | 13.15        | 9.78       | 2.15      | 0.55     |
| +          | 1/8             | 47.6        | 379.20               | 18.46        | 11.57      | 3.27      | 0.80     |
| +          | 1/4             | 49.0        | 484.77               | 25.18        | 13.08      | 4.75      | 0.98     |
| +          | 1/3             | 54.4        | 631.75               | 30.72        | 17.83      | 5.02      | 2.75     |
| Contrast   |                 |             |                      |              |            | Probability |
| Sand vs. sand + 1/4 leonardite | 0.374 | 0.636 | 0.696 | 0.732 | 0.807 | 0.915 |
| Sand vs. sand + fertilizer | 0.034 | 0.083 | 0.085 | 0.014 | 0.215 | 0.671 |
| Fertilizer vs. 1/4 leonardite | 0.114 | 0.123 | 0.141 | 0.021 | 0.298 | 0.749 |
| Rate of leonardite: 0 to 1/3 |                 |             |                      |              |            | Deviations from linear |
| Linear response | 0.022 | 0.004 | 0.011 | 0.006 | 0.038 | 0.041 |
| Deviations from linear | 0.789 | 0.800 | 0.938 | 0.277 | 0.911 | 0.266 |

Leonardite alone had no effect on plant height, total leaf area, shoot or root fresh weight, or shoot or root dry weight; however, when combined with fertilizer, as little as 1/64 leonardite (v/v) significantly increased response over the application of fertilizer alone. The most significant findings are the increases in growth that were achieved by applying both leonardite and a complete fertilizer—increases far greater than that produced by the application of fertilizer alone. Leonardite appears, then, to enhance nutrient uptake by tomato roots, possibly by increasing cation exchange capacity or acting as a chelator of both macro- and micronutrients.

Further tests with various fertilizer rates and natural soil are warranted; however, tests should include detailed characterization of the materials employed so that specific recommendations can be made.

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