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Root–soil adhesion as affected by crop species in a volcanic sandy soil of Mexico

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Abstract

Field observations have shown that root residues maintain root-adhering soil for several months after harvest. The aim of this work was to compare post-harvest effect of *Amaranthus hypochondriacus* (amaranth), *Phaseolus vulgaris* (common bean) and *Zea mays* (maize) roots on root-adhering soil, aggregation and organic carbon content. The experimental site was located on a volcanic sandy soil (Typic Ustifluvent) in the Valley of Mexico. In 1999 and 2000, maize had the highest root mass (92 and 94 g m^{-2}) and the highest root-adhering soil (9051 and 5876 g m^{-2}) when a root–soil monolith of 0.20 m × 0.20 m × 0.30 m was excavated after harvest. In contrast, bean roots (2 and 5 g m^{-2}) had only 347 and 23 g m^{-2} of adhering soil per monolith in each year. Amaranth had intermediate values between maize and bean. Dry soil aggregate classes (<0.25, 0.5, 1, 2, 5 and >5 mm) were similarly distributed among the three species. The sum of the three soil macro-aggregates classes >1 mm was 0.1 g g^{-1} in both years. Neither water stability of the 2–5 mm aggregates (0.05–0.09 g g^{-1}) nor soil organic C (SOC) in three aggregate classes (<0.25, 1–2 and >5 mm; mean 14.6 mg g^{-1}) was affected by species ($P < 0.05$) in either year. Observations of thin sections (10× and 40×) revealed absence of macro-aggregates under maize. Soil compaction was attributed to high mass of maize roots in the sampled soil volume. Root systems sampled after harvest had the capacity to maintain a well structured soil mass, which was proportional to root mass. Root-adhering soil measured in the field could be used to select species promoting soil adhesion by roots.

Keywords: Rizospheric soil; Volcanic soil; Micromorphology; Valley of Mexico; Entisol

1. Introduction

In the Valley of Mexico, where human population density is very high, efforts to avoid soil erosion help to maintain soil quality and reduce airborne soil particles. Hillside agriculture in the Valley of Mexico is dominated by rainfed monoculture systems on sandy soils prone to wind and water erosion. Plant residue management and tillage are important factors for reducing erosion. The structure of sandy soils formed from volcanic ash is dominated by a loose arrangement of sand and silt particles. The low content of clay in these soils constrains the formation of micro and macro-aggregates (Tisdall and Oades, 1982; Oades, 1993). De León-González et al. (2000) found that organic matter applied as compost increased macro-aggregates, but not aggregate stability. We have observed that soil adheres to maize roots several months after harvest (Photo 1). The

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Photo 1. Root-stalk maize residue showing adhering soil; Tulyehualco, Mexico (May 1998; six months after harvest).

adhesiveness of sand particles and micro-aggregates (<250 μm) to roots is a process involving bacterial exudates (Angers and Chenu, 1997; Olsson and Persson, 1999), fungal hyphae (Degens et al., 1996; Tisdall et al., 1997) and roots themselves (Tisdall and Oades, 1982). Roots produce an enmeshment of soil mineral material and help to stabilize the soil during plant growth (Tisdall and Oades, 1982). Forster (1990) and Oades (1993) reported the role of roots in stabilization of sandy soils. However, the literature contains little information on root-adhering soil during the post-harvest period and consequently little is known about the way decaying roots after harvest contribute to soil structure, especially for volcanic soils.

Assessment of root-adhering soil during the post-harvest period could be useful to select more appropriate crop systems as was suggested by Oades (1993), mainly in regions having sandy soil texture susceptible to erosion. Our objective was to compare the abundance of root-adhering soil (post-harvest) of three cultivated species in the Valley of Mexico. Aggregate formation, aggregate stability, and aggregate soil organic carbon (SOC) were analysed to study the short-term effect of roots on these variables.

2. Materials and methods

2.1. Climate and soil characteristics

The experimental site was located in the southern part of the Valley of Mexico (19°15′N, 99°13′W, at 2280 m, altitude). Soil (depth > 2 m) was a Typic Ustifluvent (Soil Survey Staff, 1999), abundant in volcanic ash, showing a low degree of alteration $[(\mathrm{Al}+\mathrm{Fe})^{-2}$ oxides, $1.1\ \mathrm{mg\ g^{-1}}]$ (van Reeuwijk, 1995). Clay, silt and sand contents were 70, 140 and 790 $\mathrm{mg\ g^{-1}}$, respectively. Low structural stability and other soil properties were reported previously (De León-González et al., 2000). Temperature and precipitation at the site are shown in Table 1.

2.2. Experimental units and statistical design

The experimental unit was a small plot (0.8 m × 0.8 m) in which one hill was manually sown with one of the following three species: amaranth, common bean and maize (10, 5 and 5 seed per hill) as monoculture the first week of June 1999 and 2000. The experimental design was completely randomised. Each treatment was repeated 10 times. Cultivars were "Poblano" bean (indeterminate growth, black grain), "Tulyehualco" amaranth (late and tall) and advanced line CMT939011 maize released by CIMMYT. Fertilization (80 $\mathrm{kg\ ha^{-1}}$ N, 40 $\mathrm{kg\ ha^{-1}}$ P, 0 $\mathrm{kg\ ha^{-1}}$, K) and weed control were manual. The experimental site received application of amaranth and maize residues (approximately 3 $\mathrm{t\ ha^{-1}}$) during the last 10 years.

2.3. Root characteristics and root-adhering soil

At the end of the 1999 and 2000 growing seasons, plants were cut at 3 cm above the soil surface to extract root–soil samples. Bean plants were harvested on October 30 and amaranth and maize plants on December 20. Soil water content at sampling time in 1999 and 2000 was 144 and 151 $\mathrm{mg\ g^{-1}}$ under amaranth, 182 and 189 under bean and 160 and 167 under maize. A metallic frame (0.2 m × 0.2 m × 0.3 m) centered over the plant was used to extract the root–soil samples. De León et al. (1997) showed that the root-zone was concentrated in the arable layer (0–0.3 m

Table 1
Monthly rainfall (mm) and temperature (°C) in Tulyehualco, Mexico, in 1999, 2000 and over the long-term

Month	Rainfall			Temperature		
	Long-term	1999	2000	Long-term	1999	2000
January	2	0	0	12.8	13.3	13.0
February	1	0	0	14.8	14.9	14.4
March	7	2	12	16.8	16.9	16.2
April	21	10	20	18.8	18.3	18.1
May	33	9	83	19.8	18.8	20.0
June	130	44	213	20.9	20.0	19.8
July	129	170	142	19.7	18.2	18.4
August	93	161	74	19.2	18.8	17.1
September	94	101	24	19.8	19.5	16.9
October	50	53	28	17.1	17.2	15.0
November	7	7	0	15.1	14.1	16.2
December	0	0	0	12.8	13.0	12.0