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Availability and uptake of trace elements in a forage rotation under conservation and plough tillage

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ABSTRACT

After 14 years under conventional plough tillage (CT) or conservation minimum tillage (MT), the soil available Al, Fe, Mn, Cu, and Zn (0–5, 5–15, and 15–30 cm layers) and their plant uptake were evaluated during two years in a ryegrass-maize forage rotation in NW Spain (temperate–humid region). The three-way ANOVA showed that trace element concentrations in soil were mainly influenced by sampling date, followed by soil depth and tillage system (35–73%, 7–58%, and 3–11% of variance explained, respectively). Excepting for Fe (CT) and Al (CT and MT), the elemental concentrations decreased with depth, the stratification being stronger under MT. For soil available Al, Fe, Mn, and Cu, the concentrations were higher in CT than in MT (5–15 and 15–30 cm layers) or were not affected by tillage system (0–5 cm). In contrast, the available Zn contents were higher in MT than CT at the soil surface and did not differ in deeper layers. The concentration of Al, Fe, and Cu in crops was not influenced by tillage system, which explains 22% of Mn variance in maize (CT > MT in the more humid year) and 18% of Zn variance in ryegrass (MT > CT in both years). However, in the summer crop (maize) the concentrations of Fe, Mn, and Zn tended to be higher in MT than in CT under drought conditions, while the opposite was true in the year without water limitation. Therefore, under the studied conditions of climate, soil, tillage, and crop rotation, little influence of tillage system on crop nutritive value would be expected. To minimize the potential deficiency of Zn (maize) and Cu (maize and ryegrass) on crop yields the inclusion of these micro-nutrients in fertilization schedule is recommended, as well as liming to alleviate Al toxicity on maize crops.

1. Introduction

In Europe, research on conservation tillage has been mainly focussed in semi-arid areas, where these management practices reduce soil erosion and improve water supply to plants and crop yield (De Vita et al., 2007; Lampurlanés et al., 2002; Martín-Rueda et al., 2007). Consequently, despite its potential environmental and economic advantages, little information is still available for temperate areas on conservation tillage effects in the soil-plant system (Gruber et al., 2012; Soane et al., 2012).

In Spain, around 89,000 ha are cultivated with forage maize (*Zea mays* L.), two-thirds of this surface being located in the northwestern temperate humid zone (MARM, 2009) where it is the most common crop under conservation tillage, mainly in maize–italian ryegrass rotations. For this crop rotation, conservation tillage has economic and timeliness advantages without detrimental effect on forage yields (Bueno et al., 2007). Moreover, conservation practices improved the physical, chemical, and biological properties in the topsoil layer under this forage rotation (Bueno et al., 2006; Díaz-Raviña et al., 2005; Gómez-Rey et al., 2012).

Compared with conventional ploughed fields, soil disturbance under conservation tillage management (without soil inversion) was reduced. As a consequence, the interaction of soil with crop residues and fertilizers decreased, leading to changes in the distribution of nutrients along the soil profile, with higher levels in the topsoil (Edwards et al., 1992; Franzluebbers and Hons, 1996; López-Fando and Pardo, 2009; Martín-Rueda et al., 2007; Wright et al., 2007). Moreover, timing of nutrient release was also affected (Houx et al., 2011) with possible effects on nutrient availability to plants and, therefore, on nutrient disequilibrium and fertilizer requirements (Holanda et al., 1998; Yin and Vyn, 2004). However, until present time, published studies on the effect of tillage on trace elements in soils and crops are scarce (Lavado et al., 2001; López-Fando and Pardo, 2009; Stanislawska-Glubiak and Korzeniowska, 2011; Stanislawska-Glubiak et al., 2009), and the few available reports showed contradictory results probably due to the interaction with soil type, crop species, and fertiliser practices (Watson et al., 2012). While Westermann and Sojka (1996) did not

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find differences in soil trace concentration among tillage systems, other studies reported higher levels of Mn and Zn under conservation tillage than under ploughing tillage (Edwards et al., 1992; Franzluebbers and Hons, 1996; Loke et al., 2013; López-Fando and Pardo, 2009; Martín-Rueda et al., 2007; Rhoton, 2000) and the opposite tendency for Fe (López-Fando and Pardo, 2009; Rhoton, 2000) and Cu (Loke et al., 2013; Rhoton, 2000). Although tillage practice can modify trace element concentrations in crops (Stanislawska-Glubiak and Korzeniowska, 2009), no differences on Mn, Cu, and Zn concentration have also been reported for barley straw (Martín-Rueda et al., 2007), sorghum (de Santiago et al., 2008), and flax (Grant et al., 2010). These contrasting results could be related with soil and crop characteristics, but also with meteorological conditions during the growing season because higher crop levels of Cu, Zn, Mn, and B have been reported for zero-tillage under drought conditions and for ploughing tillage when water supply was good (Stanislawska-Glubiak et al., 2009).

Accordingly, the working hypothesis is that, compared with ploughing tillage, conservation tillage changed the soil trace elements distribution with depth and affected yields and Al, Fe, Mn, Cu, and Zn contents of crops. Thus, present study aimed to evaluate the long-term effect of two tillage practices (conventional and minimum tillage during 14 years) on soil trace elements levels, crop yields, and plant nutrient contents in a ryegrass-maize forage rotation.

2. Material and methods

2.1. Site description

The experimental field was located in the Gayoso-Castro farm (43° 06′N, 7° 27′W, 420 m a.s.l.) at Castro de Ribeiras de Lea (Galicia, NW Spain). The area has a temperate and rainy climate. During the study period (October 2006– 2008), at the meteorological stations of As Rozas, Rubiás, and Lugo, located within a radius of 17 km from the farm and at similar altitude, rainfall mainly occurred in the October–June period (Fig. 1). The rainiest month was October 2006 (Meteogalicia, 2013). The soil is a Gleyic Phaeozem (IUSS, 2006) developed over sandy-clayey deposits, with sandy loam topsoil (around 70% of sand), acidic pH_{H_2O} (about 5.5), and an organic C content of 3.1–7.9 g kg^{-1}.

Since 1994, a rotation of silage maize (*Zea mays* L.) and Italian rye-grass (*Lolium multiflorum* L.) has been annually cultivated in two adjacent areas with different tillage system: conventional plough tillage (CT) and conservation minimum tillage (MT). Each area was divided in nine replicate plots (4 × 3 m; 1 m separation). Maize was sown in rows 0.75 m apart (appr. 95,000 plants per ha^{-1}, 4 rows per plot) in late May and harvested in late September, while rye-grass was sown in rows 0.17 m apart (40 kg ha^{-1}, 17.5 rows per plot) in late October and harvested in early May. In the MT treatment, before maize sowing, the adventitious vegetation was destroyed with glyphosate (36%, at a dose of 5 L ha^{-1}). In the MT system, after 8-years of no-tillage the management was changed to minimum tillage to revert the problem of increasing soil compaction and decreasing maize emergence, and the soil was loosened with a bent-leg subsoiler to a depth of 30 cm. In the CT treatment, the soil was ploughed at 25–30 cm with a reversible plough twice a year (May and October), to incorporate crop residues and to prepare seed bed. Further agrochemical treatments were similar for both tillage systems. During the maize cultivation, the plots were treated with herbicides (33% acetachlor and 16.5% atrazine, 4 L ha^{-1}), insecticide (48% clorpiriphos, 0.33 L ha^{-1}) and NPK 9-18-27 fertilizer (N: 63 kg ha^{-1}; P: 126 kg ha^{-1}; K: 189 kg ha^{-1}). During the rye-grass cultivation, the plots received NPK fertilizer in early October (N: 27 kg ha^{-1}; P: 54 kg ha^{-1}; K: 81 kg ha^{-1}) and NH_4NO_3 fertilizer in early March (N: 81 kg ha^{-1}).

2.2. Soil and plant sampling

Soil samples were collected just after rye-grass (May 2007 and 2008) and maize (October 2007 and 2008) harvesting. In each plot, soil (0–5, 5–15, and 15–30 cm depth) was taken with a stainless steel probe (4 cm internal diameter) from 8 points uniformly distributed between the rows; afterwards it was thoroughly mixed to obtain a composite sample per plot, sieved (<2 mm) and air dried. Soil water-holding capacity was determined in a Richards membrane-plate extractor at a pressure of 10 kPa. Soil texture was determined (on the <2 mm soil fraction) by the international mechanical analysis method.

Plant sampling to determine biomass and respective nutrient contents was performed in May (rye-grass) and in October (maize) of 2007 and 2008. For calculating the aboveground biomass, all plants of the plot were cut at the base and weighted. Ryegrass yielded 3158 (CT) and 3114 kg ha^{-1} (MT) in 2007 and 4425 (CT) and 7903 kg ha^{-1} (MT) in 2008. For maize, in 2007 the productions were 6613 (CT) and 6641 kg ha^{-1} (MT), while in 2008 they were 4755 (CT) and 7313 kg ha^{-1} (MT).

For chemical analysis, only plants from the plot center (75 cm inward from the edge) were considered, which were homogenized and crushed *in situ*, and a subsample was taken for chemical analysis. The subsample was dried at 60 °C for 10 h and newly crushed to a size of less than 4 mm.

2.3. Chemical analysis

The dry matter content of soils and plant material was assessed by oven-drying subsamples at 110 °C to constant weight. Soil total C was measured on finely ground samples (<100 μm) with an elemental analyser (Carlo Erba CNS 1508). For available trace elements analyses, soils (10 g) were shaken for 2 h with an extracting solution of 1 mol NH_4Ac and 0.005 mol DTPA (1:5 soil to solution ratio); the extracts were filtered through cellulose filter paper and then analysed for trace elements (Al, Fe, Mn, Cu, and Zn) by simultaneous ICP-OES (Varian Vista Pro, Mulgrave, Australia).

The plant material was finely ground (<100 μm) for chemical analysis. For determining the total nutrient content of plant material, a subsample (500 mg) was digested for 55 min with 8 mL of 65% HNO_3 and 25 mL of 30% H_2O_2 in Teflon containers in a high performance microwave digestion unit (Milestone 1200 Mega, Sorisole, Italy). Once cooled, the solutions were filtered through quantitative cellulose filter paper, transferred to 25 mL volumetric flasks, and made to volume with water. The total trace elements content (Al, Fe, Mn, Cu, and Zn) was measured by simultaneous ICP-OES.

Analytical-grade chemicals were obtained from Merck Chemical Co., quantitative cellulose filter paper from Filter-laboratory (1242, 90 mm diameter), and all aqueous solutions were prepared with type I water (ASTM, 2008). All analyses were carried out in duplicate, and the mean of both analyses was used in the statistical procedure.

2.4. Calculation and statistical analysis

Data of soil and plant variables were statistically analysed by three-way and two-way ANOVA, respectively, with tillage system, soil depth and sampling date as factors for extractable soil nutrients and with tillage system and date for concentration and content in plants. After checking the equality of variances among groups with Levene's test, significant differences among their means were established at $P < 0.05$ using the Bonferroni's test for multiple comparisons. With unequal variances, the original data were subjected to the Tukey's ladder of power, or to Cox-Box transformations, to obtain equality of variances and then signifi-