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# Patterns in phosphorus and corn root distribution and yield in long-term tillage systems with fertilizer application

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ABSTRACT

The distribution of phosphorus in the soil profile as a function of soil tillage, fertilizer management system and cultivation time is strongly related to root distribution. As the dynamics of this process are not well understood, long-term experiments are useful to clarify the cumulative effect through time. The study evaluated an 18-year-old experiment carried out on Rhodic Paleudult soil, located in Rio Grande do Sul state – Brazil, with cover crops (black oat and vetch) in the winter and corn in the summer. In the 0- to 20-cm layer, the amounts of clay, silt and sand were 22, 14, and 64 g $kg^{-1}$, respectively. This layer had a mean slope of 3%. The mean local annual rainfall is 1440 mm. The climate is subtropical with a warm humid summer (Cfa), according to the Koeppen classification. The treatments consisted of three soil managements (conventional tillage, no tillage and strip tillage) and three application modes (broadcast, row and strip) for triple superphosphate and potassium chloride fertilizers. Data for phosphorus and root distribution in the soil from the 1989/90, 1999/00 and 2006/07 growing seasons were used. Phosphorus stratification occurred through time, irrespective of soil and fertilizer management, mainly in the 0- to 5-cm layer. The tillage and fertilization systems promoted significant differences in the Pi and Pt fractions up to a depth of 20 cm. For the Po fraction, significant differences were found only in the 0- to 5- and 15- to 20-cm layers. Inorganic phosphorus accumulated in the fertilized zone (0–10 cm), with higher intensity in the no-tillage system under row fertilization with values around 150 mg $dm^{-3}$. Root distribution presented a strong positive relationship with phosphorus distribution, exhibiting redistribution in the soil profile through time. This redistribution was accompanied by increases in organic phosphorus and total organic carbon content. Corn grain yield was not affected by long-term tillage systems.



## 1. Introduction

The concept that proper soil tillage practices result in profitable and workable systems is already well accepted in Brazil (Landers, 1999). Thus, the widespread adoption of no-tillage (NT) systems in the national territory (FEBRAPDP, 2008) has brought new insights regarding the dynamics of the soil–plant–atmosphere system. The time of NT adoption requires special attention, since a major part of the changes that affect soil quality are gradual and therefore not detected in short-term studies (Calegari et al., 2008).

The factors that contribute to soil sustainability under long-term NT are physical, chemical and biological in nature (Kladivko, 2001). Among these, chemical stratification with time affects nutrients with low mobility in the soil, such as phosphorus (P) (Eltz et al., 1989).

Although the P accumulation in superficial layers of soils under long-term NT is already well documented (Rheinheimer et al., 2002; Rheinheimer and Anghinoni, 2003), this stratification can achieve different depths. Stratification ranges from the extreme top soil (0- to 2.5-cm layer; Eltz et al., 1989) up to 5 cm (Cowie et al., 1996) or 10 cm deep (Selles et al., 1998). Such differences are likely related to the duration of P redistribution in the soil profile, in addition to the degree of P saturation at exchange sites (anion exchange capacity) and the improvement of soil attributes under NT. NT promotes increases in organic matter content stimulating root growth and soil micro- and mesofauna activity (Sá, 1994). To understand this new P dynamic established in the soil with time (Dwyer et al., 1996), it is crucial to evaluate P distribution in the soil profile as well as the forms in which P accumulates and how roots distribute with depth. The topics requiring urgent

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investigation in Brazil include increases in P content throughout the profile and the form in which this nutrient moves through the soil (Anghinoni, 2007).

The effects of soil tillage systems on root distribution throughout the soil profile (Taylor, 1983), in combination with the difficulty of evaluating root systems in field trials (Amos and Walters, 2006), render studies on root behavior under tillage systems scarce. Long-term no tilling can influence root growth rate in a positive manner. However, divergent behavior has been observed. Sometimes roots tend to accumulate in the superficial layer (Taylor, 1983), and sometimes roots develop more deeply with time (Qin et al., 2005).

The present study aimed to identify the role that time may play in the effects of soil management systems and fertilizer application on the distribution of phosphorus and corn roots in the soil profile, as determined by a long-term experiment.

## 2. Materials and methods

The experiment was established in 1988 at the Agronomic Experimental Station (30°05′22″S latitude and 51°39′08″W longitude) of the Federal University of Rio Grande do Sul, in Eldorado do Sul county, Rio Grande do Sul state (Brazil). The experiment was performed on a Rhodic Paleudult (Soil Survey Staff, 1999) clay loam soil. In the 0- to 20-cm layer, the amounts of clay (<0.002 mm), silt (between 0.002 and 0.02 mm) and sand (>0.02) were 22, 14, and 64 g kg$^{-1}$, respectively. The amounts of dithionite-citrate-bicarbonate-soluble Fe, ammonium oxalate-soluble Fe and caulinite were 36, 109 and 720 g kg$^{-1}$, respectively. This layer had a mean slope of 3%. The mean local annual rainfall is 1440 mm. The climate is subtropical with a warm humid summer (Cfa), according to the Koeppen classification (Kottek et al., 2006).

The experimental area was maintained as native grassland until 1974. During the following two years (75/76), the soil was tilled (conventional tillage) and kept fallow. The soil remained fallow until initiation of the experiment (1988), with the exception of one cultivated crop: black oat (*Avena strigosa*, S.), cultivated under conventional tillage in 1985.

In May of 1988, 3.4 tons of lime (aiming a 6.0 pH) was applied being incorporated over the entire experimental area to 15-cm by one-disk plowing and two-disking. Liming was followed by cultivation of black oat. Subsequent to the oat harvest in October, we applied the experimental treatments (soil tillage systems and fertilizer applications) and then planted corn (*Zea mays* L.) seedlings. Before treatment application, the primary chemical attributes of soil in the 0- to 15-cm layer were pH (1:2 soil/water ratio) 5.2, P and K (Mehlich 1) 2.5 and 132 mg dm$^{-3}$, respectively, and organic matter content of 30 g kg$^{-1}$ soil. Particularly soil pH values were 5.5 (0–5 cm), 5.1 (5–10 cm), 5.0 (10–15 cm), respectively.

The tillage systems were conventional tillage (CT – one-disk plowing at a 15-cm depth and two-disking), strip tillage (ST – plowing a 20-cm wide strip to a 15-cm depth in the corn rows) and no tillage (NT – opening a row of 5–8 cm depth in the corn rows). Triple superphosphate (16.5% of P) and potassium chloride (50% of K) were applied as broadcasts (Brd – on the surface of the plot mixed with the soil in conventional tillage and remaining on the soil surface in strip and no tillage), strips (Stp – in a 20-cm wide strip in corn rows, incorporated in the soil in conventional tillage and strip tillage, and remaining on the surface in no tillage) and rows (row – to a 5- to 8-cm depth opened in rows for all tillage treatments). In strip tillage, fertilizer application (in the strip and in the row) and corn seedling planting were consistently performed in the same place inside each experimental plot. Consistency was maintained from year to year by using local markers.

The experiment was carried out in a randomized block design in a 3 × 3 bi-factorial scheme separated by 5-m strips in a split plot design with soil tillage systems in the main plots (24 m × 12 m) and fertilizer applications in the split-plots (12 m × 8 m) with three replicates. Since October 1988, the following cropping sequence was used: corn during the spring and summer and black oat + vetch (*Vicia sativa*) during the fall and winter with liming reapplications occurring every four years following the first application (1988). Liming applications (40% of CaO and 10% of MgO) were designed to achieve a soil pH of 6.0 in order that 3.0, 2.9, 2.9 and 2.8 tons were applied in the 1991/92, 1995/96, 1999/00 and 2002/04 growing seasons. Lime was surface-applied in NT and incorporated (arable layer) in the conventional and strip tillage systems. Biomass production of black oat and vetch did not differ among tillage systems or throughout the years presenting values, in average, of 4.5 tons ha$^{-1}$.

The experiment was carried out for 18 years using the same procedures. Thus, corn was sown after tilling and fertilizer application with 5–7 plants per meter with 1 m between rows, distance between rows was maintained even (1 m) for the 18 years. Important aspects of the three growing seasons (1989/90, 1999/00 and 2006/07) are detailed out below.

### 2.1. 1989/90 and 1999/00 growing seasons

For 1989/90, 150, 35 and 40 kg ha$^{-1}$ of nitrogen (N), phosphorus (P) and potassium (K) were applied as urea (45% of N), triple superphosphate, and potassium chloride, respectively. Phosphorus and potassium were applied simultaneously. Nitrogen was top dressed at 25, 61 and 67 days after emergence (DAE); 50 kg ha$^{-1}$ was applied each time. The third application was required due to the potential losses following ammonia volatilization that may have occurred during the second application as a result of the high temperatures and low soil moisture. The corn, a C 511-A Cargill® hybrid, was sown nine days after the fertilizers were applied (09/19/89). During the corn cycle, two supplementary irrigations of 20 and 30 mm, respectively, were applied at 25 and 69 DAE. Both irrigations were applied after N top-dressing in such a way that the corn received about 740 mm of water during its cycle (after considering the 690 mm of rainfall).

In the 1999/00 season, the same rates of fertilizer were applied, including two split applications of urea. A similar amount of water (760 mm through two overhead irrigations) was furnished during the crop cycle. However, during this crop season the 6069 Pioneer® corn hybrid was used (10/10/99).

### 2.2. 2006/07 growing season

For the 2006/07 growing season, the corn was sown (Pioneer 30R50® hybrid) on October 20, 2006. Before applying the treatments, the main chemical attributes for the 0- to 15-cm soil layer were: pH (1:2 soil/water ratio) 5.6, organic matter content of 30 g kg$^{-1}$; available P and K (Mehlich 1) of 8.0 and 130 mg dm$^{-3}$, respectively, and 0, 4.0 and 1.8 cmol$_c$ dm$^{-3}$ of exchangeable (KCl 1 mol L$^{-1}$) $Al^{+3}$, $Ca^{+2}$ and $Mg^{+2}$, respectively. Based on these results, 60, 65 and 83 kg ha$^{-1}$ of urea (N), triple superphosphate (P) and potassium chloride (K), respectively, were applied. These levels were applied to obtain a corn yield higher than 8 Mg ha$^{-1}$, according to the official fertilizer state recommendations (CQFS RS/SC, 2004). At 15 and 35 DAE, 60 kg ha$^{-1}$ of N as urea were top dressed. The corn received six supplementary irrigations of 25 mm each during its cycle in addition to the 721 mm furnished by rain. The corn seedlings thus received a total of 871 mm of water throughout the growth cycle.

### 2.3. Sampling and analysis

To determine phosphorus and root distribution in the soil profile during the corn grain filling period (dough stage), soil monoliths were sampled in Jan/90, Jan/00 and Jan/07. Samples