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Introduction

Accurate assessment of soil organic carbon (SOC) stock and its temporal variation is crucial in order to determine the effect of cropping practices such as tillage. The benefit of no-tillage on SOC storage is still a controversial issue and recent meta-analyses have shown that this benefit was not as important as thought ten years ago. Methodological improvements have been proposed (*e.g.* Olson *et al.*, 2014) to make unbiased SOC estimates: measuring stocks at time 0, determining bulk density, sampling below the maximum depth affected by soil tillage, and measuring SOC over time, in order to make diachronic rather than synchronic studies. These recommendations were applied to one of the oldest tillage experiment (47 years) carried out in the world, at Boigneville in northern France.

Material and methods

The soil tillage experiment was initiated at Boigneville (48°19′37″N, 2°22′56″E) in 1970. It is managed by ARVALIS. It compares 3 tillage treatments: annual full inversion tillage (FIT), shallow tillage (ST) and no-till (NT), crossed with 6 crop managements varying in straw management (export or return), crop rotation (2 or 4 year rotation) and catch crop (absence or presence), in a randomized block system with four blocks. Full details are given by Dimassi *et al.* (2014). In this paper, we will consider only the tillage effects, averaging the crop management treatments, since no interaction was found between these two factors.
The yield of the various crops (wheat, maize, sugarbeet, barley, fababean) was recorded on each plot at harvest. The soil was sampled at 12 dates between 1970 and 2017, on average every 4 years, from 0 to 33 cm, *i.e.* 5 cm deeper than the maximum ploughing depth. Results from the period 1970-2011 are detailed in Dimassi *et al.* (2014).
A new sampling campaign was achieved in 2017. Soil was sampled at 144 sites to a depth of 60 cm using a tubular gauge (6 cm diameter). Each soil core was divided into 7 layers (0-5, 5-10, 10-15, 15-28, 28-33, 33-40 and 40-60 cm) which were air dried, weighed and analysed for C and N content. Bulk densities were measured in 72 sites using a gamma-densitometer (5-40 cm) and the cylinder method (other depths).
Calculations of SOC stocks during the 47 years of the experiment were made on equivalent soil mass basis (Ferchaud *et al.*, 2015) using a dedicated *R* package (called *SEME*). The effect of treatments on SOC stocks was tested by analysis of variance (ANOVA) using a linear mixed effect model (*nlme* package).

Results and discussion

In 1970, the field exhibited a very small spatial variability: the mean SOC stock calculated between the three tillage treatments was 44.65 ± 0.31 t ha^{-1} in the reference layer (about 0-32 cm, corresponding to a soil mass of 4600 t/ha) and not significantly different. The initial SOC concentration was almost constant down to 28 cm (previous ploughing depth) and decreased rapidly below 28 cm (Fig. 1). In 2017, SOC concentration differed widely between tillage treatments: it markedly increased in the upper layer (0-10 cm) of NT and ST and also decreased significantly below 10 cm.

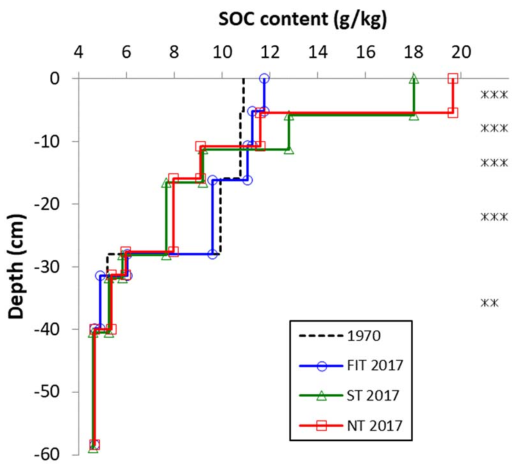

Figure 1. SOC concentration profile measured in 1970 and 2017.

The SOC stratification was consistent with the depth of crop residue incorporation. Cumulative SOC stocks between 28 and 60 cm did not differ between treatments.

SOC stocks of ST and NT increased markedly with time in the upper layer (0-10 cm) but also decreased significantly in the layer 10-32 cm, whereas small variations were observed in the FIT treatment (Fig. 2). SOC stocks in the whole reference layer followed a rather similar evolution between treatments, with a slight increase throughout time, and no significant difference between treatments at any time.

The absence of tillage effect on SOC storage cannot be attributed to differences in crop residues since the average crop yields did not differ between tillage treatments during the whole experiment. The decrease of SOC stock in the 10-32 cm layer shows that C mineralization is active in this layer in ST and NT treatments in spite of the absence of soil tillage.

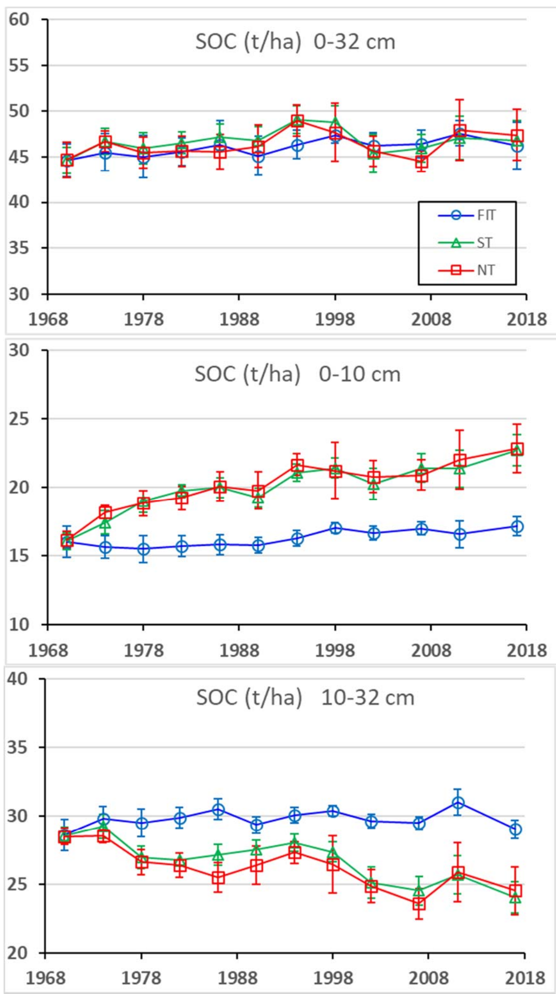

Figure 2. Evolution of SOC stocks during 47 years in three soil layers, according to soil tillage treatment.

Conclusion

This long-term experiment is a very valuable tool to analyse the effect of tillage as a single factor, contrary to conservation agriculture which may combine other factors such as longer crop rotation and permanent cover crops. The long duration, the quality of the methodological approach and the consistency of the results obtained in this diachronic study allow to make reliable conclusions on the effect of tillage on SOC storage on the long term, under these pedo-climatic conditions. Efforts to conduct similar diachronic studies in other sites should be encouraged. The *SEME* R package is available upon request.

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