

Impact of soil organic carbon content on soil filtering capacity solutes

Anna Bürger^D, Marjorie Piquet^c, Felix Moreno^B, Markus Deurer^A, Brent Clothier^A, Steve Green^A, Karen Mason^A, Ian McIvor^A, Carlo van den Dijssel^A and Siva (Sivalingam) Sivakumaran^A

^ASustainable Production: Soil, Water & Environment and Systems Modelling & Biometrics. The New Zealand Institute for Plant & Food Research Limited (Plant & Food Research), Palmerston North, 4442, New Zealand.

^BInstituto de Recursos Naturales y Agrobiología de Sevilla (IRNAS-CSIC). Sevilla, Spain.

^CENSAIA (National Engineering school of Agronomy and Food Industries), Nancy, France.

^DUniversity of Hohenheim, 70593 Stuttgart, Germany.

Abstract

Our objective was to study how soil organic carbon (SOC) influences the solute transport. To monitor the water and solution movement in soil, anion bromide has been used as a tracer. We were interested in the transport process of nitrate, because of its relevance concerning the issue of nitrogen contamination of groundwater. The study investigated soils under two different types of land use with different carbon contents. The first land use was a pair of soils under apple orchards. The second land use was permanent pasture grazed by sheep. Generally, soil properties improve with soil carbon management. This study showed the converse for the aspect of surface applied solutes under conditions where there would be the likelihood of surface ponding of water.

Key Words

Soil organic carbon, nitrate, drainage-flux meters and water.

Introduction

Agriculture and horticulture systems in New Zealand are managed according to the guidelines of either organic or integrated fruit production. In previous studies those systems have been compared in various aspects, one is the 'soil carbon management' what is defined as "land management practices that maintain or increase SOC" (Deurer *et al.* 2007). The study focused on the impact of soil carbon management on the soil filtering capacity of surface applied inert solutes. Such an inert solute is the nutrient nitrogen, which is essential for the growth of many plant species. Excess nitrogen becomes a problem if it leaches, in the form of nitrate, through the soil into the groundwater or the neighbouring rivers and lakes. Therefore it is important to know which soil characteristics are affected by nutrient leaching and what are the relevant processes. There are two kinds of nitrate in the soil, one is mineralised nitrogen from organic matter, and other is surface applied fertilizer. In this study we focused on the affect of SOC on the transport of surface applied solute.

Hypothesis 1: Due to the higher macro-porosity we presumed that the organic orchard soils would have a higher leakiness than the integrated orchard soil. Preceding studies have found that the soils aggregate size fraction from the 'non-camp' and 'camp' site were hydrophobic and have lost some capacity to rapidly absorb applied solutions (Aslam *et al.* 2009). Based on several other studies, the SOC content is positively correlated with the degree of soil water repellency. It has also been determined that the macro-aggregates from the 'non-camp' site were significantly less hydrophobic than from the 'camp' site. Previous studies have reported that water-repellent zones cause preferential flow which is defined as all phenomena where water and solutes move along certain pathways, while bypassing a fraction of the porous matrix' (Hendrickx and Flury 2001). In other words, preferential flow refers to the uneven and often rapid movement of solutes through porous media, characterized by regions of enhanced flow such as wormholes, root holes and cracks. Hypothesis 2: Based on this knowledge of water repellency we presumed that the 'camp' site with 30% more SOC would have a lower solute filtering capacity than the 'non-camp' site.

Methods

Sampling Sites

Intact soil cores (30 cm x 10 cm) were collected from four sites. The first two sites were on rows on neighbouring orchards in Hawke's Bay, New Zealand. Both soils had the same loam texture but different carbon management practises. One is an organic apple orchard system managed according to the BIO-GRO standards (<http://www.biogro.co.nz>) with regularly added compost. The other system is an integrated orchard managed according to the standards of integrated fruit production. A 0.5-m wide strip under the trees was

kept bare by regular herbicide applications. In the organic orchard the trees were grassed and regularly mowed when necessary while the strips in the integrated orchard were kept vegetation-free. In the organic system green-waste from the orchard has been applied to the topsoil once a year whereas in the conventional orchard the pruning and leaf fall were the only regular organic manure. After 12 years the topsoil (top 10 cm) of the organic orchard had with 38.8 kg SOC/m² about 30% more SOC sequestered than those of the integrated orchard with 2.6 kg SOC/m². (Aslam *et al.* 2009) The other two sites were on a sheep pasture with a loam texture like on the apple orchards. Due to the sheep habits, the paddock could be separated into areas. One area was too steep for the sheep to rest on, so was the main grazing region. These areas are called “Non-Camp” sites. The steep area was intercepted with relative even spots, thus the sheep used those areas to rest during the night. Such areas are called ‘camp-sites’ and known to accumulate sheep manure. As a consequence the topsoil (top 10 cm) of the ‘camp-sites’ sequester 8.7kg SOC/m², 30% more SOS compared to the non-camp site with 6.3 kg/cm².

Drainage flux-meters

To monitor the drainage and leaching we used drainage-flux meters. The device enables to collect and measure the volume of the drainage water. On the top of the drainage flux meter is a column which is used to collect undisturbed soil samples and also prevents the sideway flow of water and solution during the trial. The column containing the soil is “bolted” on two other assemblies. One is collecting the drainage and the other one contains a funnel, a wick, and the tipping spoon (drop-counting mechanism). To prevent soil from entering the funnel, a thin layer of diatomaceous earth is placed above the wick. The spoon under the wick is connected to a data-logger and quantifies the volume of water. To calibrate the tipping spoon a known amount of water is injected via calibration tub that ends right above the spoon. After the drainage-flux meters were loaded with the undisturbed soil samples of the study site, they were assembled under an irrigation system. For each soil category we had three replications.

The Tracer Bromide

The tracer bromide has been used to monitor the water and solution movement in the soil. Bromide is widely used as relatively conservative tracer in hydrological and biogeochemical studies, having the advantage of a very low natural background concentration in the soil (Flury and Papritz 1993). At the beginning of the trial 250 mg of potassium bromide mixed in 20g of sand was added on the top of the drainage-flux assembled meters. The flux meters have been irrigated during the day but were not irrigated at night. In the beginning the drainage was sucked out of the solution collector 3-4 times a day. Later on it was less often, because we presumed that the major ratio of bromide was already leached out. The concentration of bromide in the effluent was measured with an ion-chromatograph at Massey University, Palmerston North, New Zealand.

Results

Drainage

The water flow of the organic and integrated orchard soils, (30% different in SOC content) shows no real difference. Whereas the camp site with 30% more SOC than the non-camp site has an apparently higher drainage. Because of the different utilisation of orchards and paddock the comparisons in terms of the SOC content is suitable to only a limited extent. However, due to the same texture but higher drainage rate of the pasture soils we presume a higher macro-porosity of the paddock soil compared to the orchard soil.

Breakthrough curves

The pasture and the orchard soils come from a different land use and hence the curves look different. In the effluent of the both orchard soils the bromide appears later and in a lower concentration compared to the pasture soil. This is likely determined by higher macro-porosity of the paddock soils as hypothesised in the introduction.

An unexpected irregular concentration time trend for both orchard soils, whereas this is not the case for the pasture soils. It is conspicuous that the effluents of organic and integrated soils have a concentration decline at the same time. On closer inspection, the low concentration was measured in water samples which were taken in the morning, from the first effluent after an irrigation stop during the night. This indicates that the fluctuating concentration is caused by flow-interruption where evaporation occurs, but diffusion continues.

Earlier studies about interrupted flow have shown that the solute transport is influenced by micro-pore diffusion. The degree to which flow interruption might influence solute transport depends on the factors such

as the degree of heterogeneity, the length and the timing of interruption, and the characteristic time of diffusion, which is a function of the magnitude of the diffusion coefficient and the concentration gradient (Brusseau *et al.* 1996). Hence, we can assume that the relative constant curves of the pasture soils is mainly caused by a more homogeneous soil structure compared to the orchard soil structure. Additionally it has been said that the concentration gradient influences the degree of the non-ideal transport affected by flow-interruption. The bromide transfer through the pasture soil is so rapid that already after a short time the concentration in the effluent is quite low. Therefore the concentration gradient inside the soil is also low, this may be a secondary reason for the more consistent curve of the pasture compared to the orchard soil.

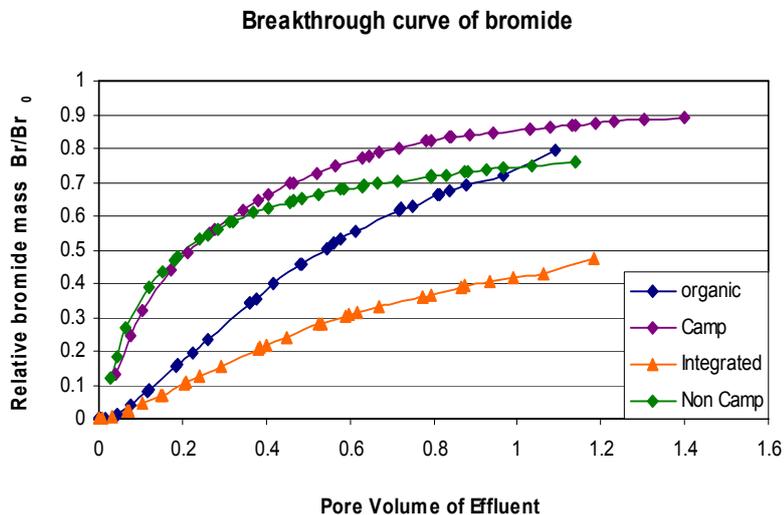


Figure 1. The Graph shows the bromide breakthrough curves for water-unsaturated soils. Relative bromide mass is the ratio of added bromide measured in the effluent. Pore volume is the ratio of the volume of effluent to the volume of fluid in the soil sample.

The breakthrough curve of the pastures rises clearly earlier and steeper compared to the orchard curves (Figure 1). Even though the pasture and orchard soils have different textures, the breakthrough curves look like as we would expect. Given that the water flow through the orchard soils is less rapid than in the pasture soils, we can explain the later appearance bromide with more matrix exchange of the solute.

In case of the orchard soils, the breakthrough curves show a continuous rise of recovered bromide, whereas a consistently higher amount of bromide is recovered in the effluent of the organic orchard soil. With a pore volume of 0.7, 45% of the added bromide had passed through the organic soil and approximately 35% from the integrated soil. The t-test showed that this is significantly different ($P < 0.05$).

The major reason for higher mobility of bromide in the organic orchard compared to the integrated orchard is likely the soil structure, with higher macro porosity caused by the increased SOC content. Due to the higher surface-to-volume ratio and connectedness of micro-pores, the interaction between solute and soil aggregates in the micro-pores is higher than in the macro-pores. Consequently we found that the SOC content is positive correlated to the leakiness of the soil for surface applied solutes.

In the case of ‘camp’ and ‘non-camp’ soils there is no difference in the beginning of the breakthrough curves. After a pore volume of 0.3, approximately 60% of bromide was recovered. Considering the fact that the soils aggregate fraction from the ‘non-camp’ and ‘camp’ site were hydrophobic and had lost some of their capacity to wet up (Aslam *et al.* 2009) we assume that the rapid bromide transport was found because of preferential flow, where the solution moves without exchange into the aggregates through the soil. Later, the breakthrough curve of the ‘camp’ site rises more than the ‘non-camp’ curve. In the end 90% of added bromide was retrieved from the ‘camp’ site and 75% bromide from the ‘non-camp’ site. We could not find a significant difference with the t-test, because we had in the end just 2 replicates for the non camp. Although the t-test has not showed a significant difference, it is most likely that the camp and non-camp have a different filtering capacity. Whether the rise of the ‘camp’ and ‘non-camp’ curves is different, both have the trend to increase much less than in the beginning, thus it seems to be an asymptotic expansion. The reason for the less rapid transport of bromide later on could be that the micro-pores and soil aggregates started to absorb water, hence the ratio of preferential flow (Clothier *et al.* 2008) was reduced.

Pertaining to the difference of the two pastures, we found that later on the solute filtering capacity of the 'non-camp' soil was higher compared to the 'camp' soil as the 'camp' site was more hydrophobic than the 'non-camp' site. Consequently we found, as with the results of the orchards, a higher filtering capacity for surface applied solutes for the soil with less SOC.

Conclusion

We studied how the soil's organic carbon content influences the soil's filtering capacity, with the goal of mimicking the leaching of surface-applied nitrate with an anion tracer. We found on two pairs of soils that the filtering capacity of the tracer was less in the soil with a higher SOC content in the topsoil. This consequently means that surface-applied nitrate would leach faster for the soil with a higher organic carbon content under these conditions where the irrigation rate would likely cause surface ponding of water on the matrix and allow access to the macroporous network. Valuing these results in terms of preferable soil quality and ecosystem service we would come to the conclusion that less soil organic carbon has the advantage of less leakiness for surface applied fertiliser when there is likely to be surface ponding. Considering, however, the nitrate which might be mineralised in the soil, it can be considered that a higher SOC content would increase the soils ability to mineralise nitrate indigenously, because the nitrate mineralisation in the soil aggregates would be positively correlated with the SOC content. Therefore we can hypothesise that there would be an improvement for the filtering capacity of mineralised nitrate, in contrast to the weaker filtering capacity for exogenously applied surface fertilisers that would be affected by a higher SOC content.

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