Systems for evaluating the correlation between soil cone penetrometer resistance and shear strength

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Abstract

The aim of this research is to study possible correlations between soil compaction (and related soil cone penetrometer resistance measurements) and shear strength normal to the field plane, required to cut the soil with a subsoiler.

A measurement system for sensing the soil cone penetrometer resistance was built mounting, on a frame fixed to the front part of a tractor, a rod and a penetration cone with a load cell. A load cell, mounted on the tractor drawbar, pulling a subsoiler, allowed to measure the shear strength normal to the field plane, required to cut the soil. Both load cells were connected, through a display, to a portable computer, where a software was used for acquiring the data of both parameters. The measured data was geo-referenced by using a DGPS mobile receiver, mounted on the tractor. After several reliability laboratory tests, the two systems were experimented on a field of inland Sicily.

The results did not show any correlation between the two studied parameters. Therefore, further tests with different soil types and conditions need to be carried out, in order to find out if the total lack of correlation was due to the particular soil conditions encountered during the tests.

"Aim of the research"

The within-field spatial variability of soil compaction can be evaluated by measuring the geo-referenced soil cone penetrometer resistance. However, in order to discover the causes of soil compaction, its temporal variability must be evaluated and, therefore, a series of measurements have to be carried out every time climate factors and especially field operations may have caused soil compaction variations.

The measurement of geo-referenced soil cone penetrometer resistance may be used for planning field operations and setting up soil tillage in precision agriculture [3].

In fact, soil compaction may strongly influence the demand of tractive performance and torque at the p.t.o. shaft of a tractor mounting tillage implements. Therefore, we decided to investigate the possible correlations existing between soil compaction (and the related soil cone penetrometer resistance) and shear strength normal to the field plane, required to cut the soil with a subsoiler [4].

"Materials and method"

A measurement system was built mounting, on a frame fixed to the front part of a Fiat 455 C track-laying tractor of 35 kW, a rod and a penetration cone with a strain-gauge load cell, for sensing the soil cone penetrometer resistance (Fig. 1) [1, 2]. The type of load cell was Tekkal ABA 300, having a nominal sensitivity of 2 mV/V and a maximum measurement force of 3 kN (Fig. 2). The cone was designed according to NEN penetrometer standard (NEN 5140:1996 nl), using the large cone size of 25.23 mm nominal diameter and 60 degree vertex angle with a 5 cm^2 base area.

Another system, consisting of a strain-gauge load cell, mounted on the tractor drawbar, pulling a subsoiler, allowed to measure the shear strength normal to the field plane, required to cut the soil (Fig. 3). The type of load cell was Hottinger Baldwin Messtechnik HBM-U1, having a nominal sensitivity of 2 mV/V and a maximum measurement force of 50 kN (Fig. 4).

Both load cells were connected, through a NBC Elettronica SD 01 display, to a RS 232 serial port of a portable computer with a sampling rate of 10 Hz. Inside the computer a ComCAP software was used for acquiring the data of both parameters.

The measured data was geo-referenced by using a DGPS mobile receiver, mounted on the tractor, in RTK mode with a computed data output rate of 0.4 Hz.

The two systems were experimented in the Department laboratory for reliability in September 2007: the calibration results of both load cells showed a linear relationship between the input force values and the output signals with a R^2 of about 1.

Relying on the satisfying results of the laboratory tests, the two systems were experimented on a field of inland Sicily, along a 0-500 mm soil profile, in order to investigate the existence of a correlation between soil compaction (and related soil cone penetrometer resistance measurements) and shear strength required to cut the soil vertically.

In February 2008 two tests (named test 1 and 2) were carried out in a field of Ventimiglia di Sicilia (Palermo), not cultivated in the previous four years and having a clay soil texture according to Miller triangle (clay 58.5%, silt 25.5% and sand 16.0%) and a water content of 17.5%.

Soil cone penetrometer resistance and shear strength normal to the field plane were measured. The soil was compacted using a Massey Ferguson 290 DT tractor of 63 kW mounting a front loader. The tractor had a wheelbase of 2.27 m, a track of 2 m and a total mass of 3580 kg [5]. The tractor front axle was fitted with 13.6 R24 tyres, inflated at 200 kPa and the rear axle with 16.9 R34 tyres, inflated at 150 kPa. Light, moderate and heavy compaction was obtained at a mean forward speed of about 1.5 m s^{-1} with 5, 10 and 20 passes, respectively.

Figure 5 shows the field experimental scheme for the four measurement paths, distant 6 m from each other.

During test 1 the soil cone penetrometer resistance was measured every 1 m along each path and also in correspondence of both the tractor tyre prints and in the middle of them, with a penetration depth of 500 mm and an operating speed of about 40 mm s^{-1}.

During test 2 the above mentioned system for measuring the geo-referenced shear strength normal to the field plane was used along the paths, using a subsoiler with only one tine (Fig. 6).

"Results"

Figure 7 shows the results of soil cone penetrometer resistance (mean values for each 50 mm depth layer) and soil shear strength normal to the field plane (moving average values with n = 21, 30, 33 and 36, respectively) along the four measurement paths.

The mean soil cone penetrometer resistance values of the various layers ranged from a minimum of about 230 N to a maximum of about 2450 N. In the great majority of the measurement points the highest values of soil cone penetrometer resistance were recorded below the 30-35 cm layer, where a soil ploughing pan was found.

The shear strength normal to the field plane ranged from a minimum of about 5900 N to a maximum of about 34900 N. The values of shear strength normal to the field plane show an almost periodical variation, probably due to previous ploughing with tractor tyre in the furrow carried out along a direction normal to the measurement paths.

Strangely, the peak values of soil cone penetrometer resistance and shear strength recorded seemed to be independent from the amount of compaction caused by the tractor (5, 10 and 20 passes). However the variation of soil cone penetrometer resistance seemed similar to that of shear strength along most of each measurement path and in correspondence of each measurement point.

Soil cone penetrometer resistance (sum of the mean values) and shear strength (raw values) in correspondence of each measurement point were found to be badly correlated, with values of R^2 equal to 0.17, 0.72, 0.14 and 0.14 for the four measurement paths, respectively. Figure 8 shows the highest correlation (R^2 equal to 0.72), found in the second measurement path.

"Conclusions"

The results did not show any correlation between soil cone penetrometer resistance and shear strength normal to the field plane. The amount of compaction caused by the tractor passes did not influence the values of cone penetrometer resistance and shear strength recorded. This may be due to the type of soil (clay) and amount of water content.

Therefore, further tests will be carried out with different soil types and conditions, in order to find out if the total lack of correlation between the cone penetrometer resistance and the shear strength normal to the field plane was due to the particular soil conditions encountered during the tests.

"Paper references"

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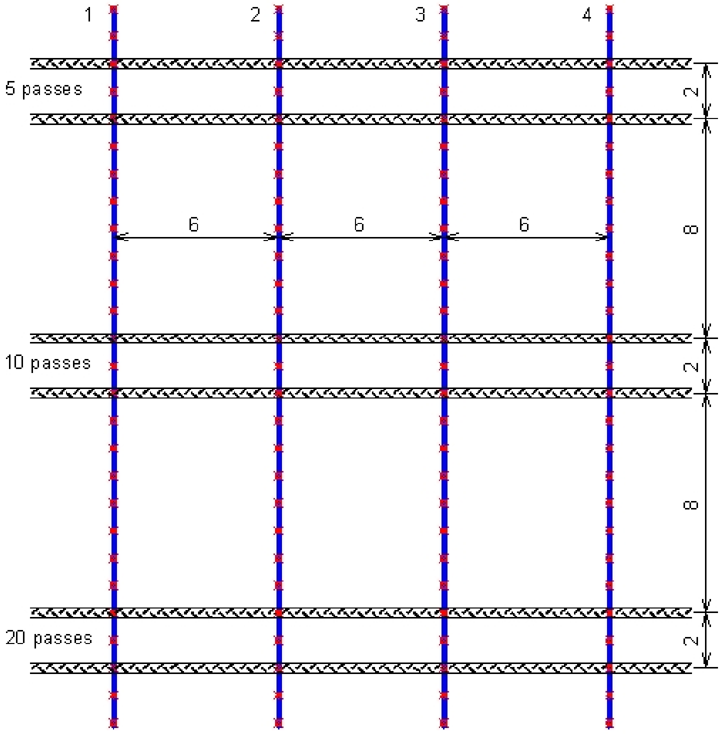
"Figure 1 – The system for measuring the geo-referenced soil cone penetrometer resistance."

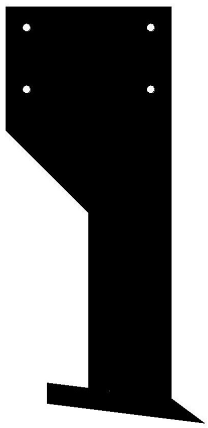
"Figure 2 – Tekkal ABA 300 load cell, connected to the penetration rod and cone."

"Figure 3 – The system for measuring the geo-referenced shear strength normal to the field plane, required to cut the soil."

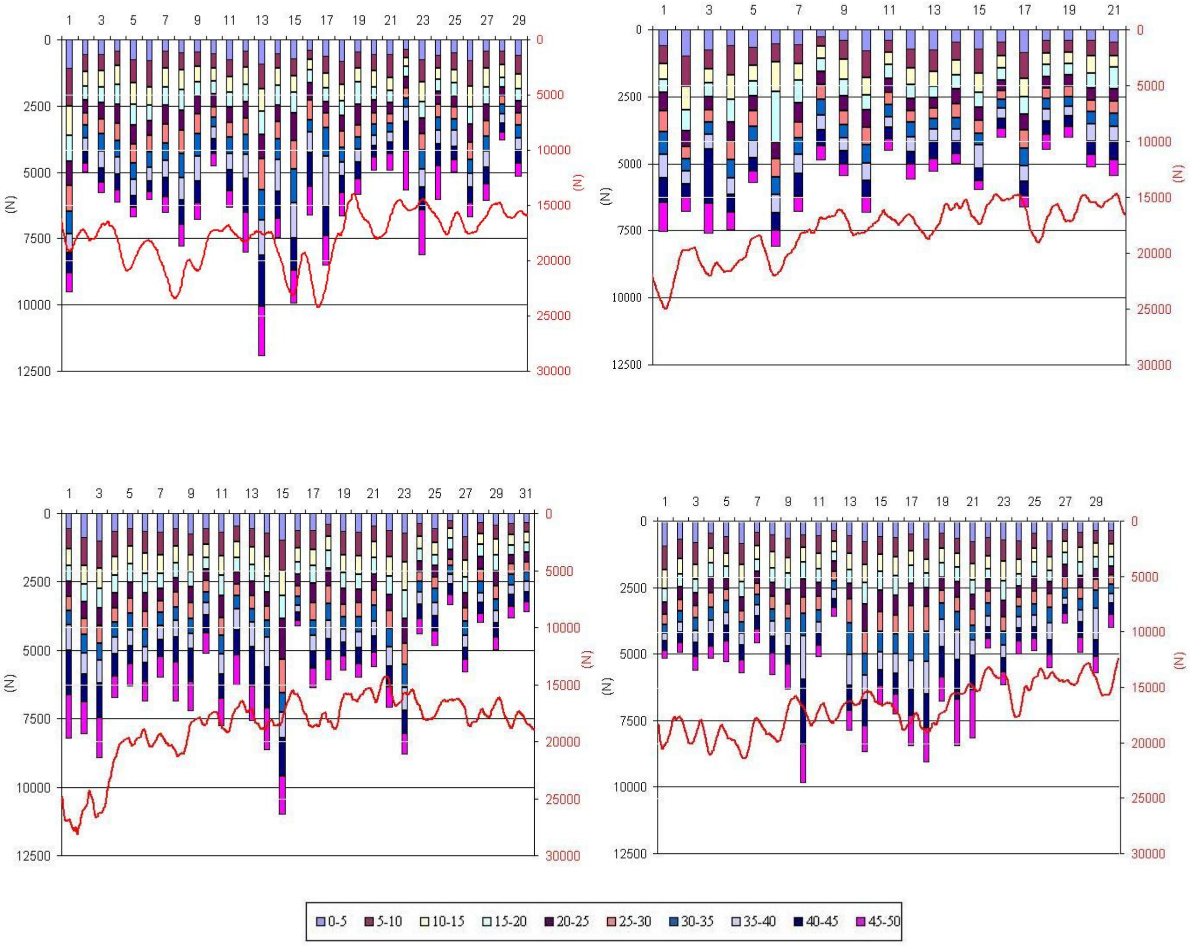
"Figure 4 – Hottinger Baldwin Messtechnik HBM-U1 load cell, mounted on the drawbar connecting the tractor with a subsoiler."



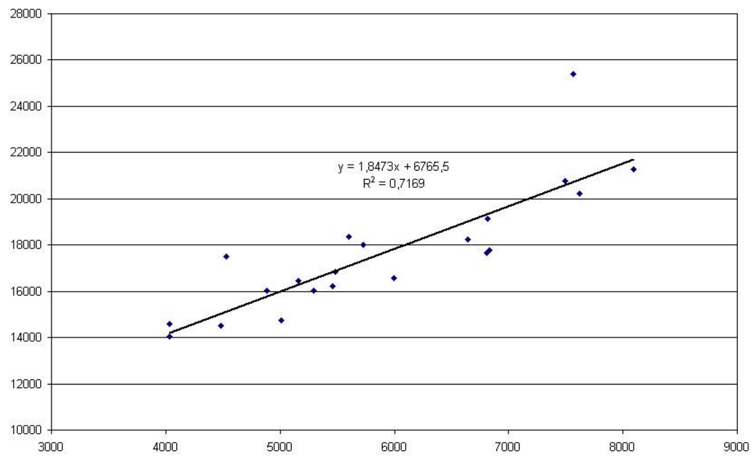
"Figure 5 – Field experimental scheme for the four measurement paths (the distances are expressed in metres)."



"Figure 6 – Profile of the subsoiler tine used during the measurement test of shear strength normal to the field plane."



"Figure 7 – Results of soil cone penetrometer resistance for each 5 cm depth layer and shear strength normal to the field plane along the four measurement paths."



"Figure 8 – Correlation between the soil cone penetrometer resistance and the shear strength normal to the field plane along the second measurement path."