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ARTIFICIAL COMPACTION GIVEN BY PENETRATION RESISTANCE IN SOILS WITH DIFFERENT USE

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ABSTRACT

Heavy agricultural machinery is major cause of one of the processes of soil degradation, compaction, which became a problem of significant proportions, especially on soils with high moisture. Excessive traffic affects soil quality and crop production, and also causes environmental problems. The paper presents the results of research conducted to determine soil compaction on three experimental fields: plot of energy willow, plot of clover and cherry orchard, while different moisture contents represent subfactor. Maximum penetration resistances were recorded at 45 cm depth, where the soil is severely compacted: 3194.5 kPa on the soil cultivated with energy willow, 2984 kPa in the orchard, respectively 3069 kPa on the plot of clover.

INTRODUCTION

Soil is a vital part of every ecosystem on Earth and one of the most important natural resources. By its functions, the soil provides us with vital goods and services to sustain life. However, the soil can be considered a non-renewable resource, because its formation is an extremely slow process. Human activities have often led to degradation of the world's soil resources, which are the basis for agriculture and sustained food security. Studies have shown that common human interventions that are causing soil degradation are: mismanagement of agricultural soil; deforestation; overgrazing by livestock; overexploitation of the vegetative cover for domestic use; bio-industrial activities [5].

European soils are threatened by multiple processes which affect their long-term ability to support such functions. Soil degradation can impact water and air quality, biodiversity, climate change, human health and food security. Most regions of the world have severely degraded soils, but the negative economic impact of soil degradation is most severe in the countries most dependent on agriculture for their incomes [11].

Compaction is a form of soil degradation mainly due to the repeated traffic of heavy agricultural machinery. Agricultural operations in both vegetable fields and orchards often occur when the soils are moist and prone to compaction [7]. This process of soil degradation has numerous negative effects: it alters soil structure, reduces water and air infiltration, increases waterlogging and surface runoff, reduces pesticide decomposition and increases pesticide leaching into groundwater, increases the erosion and sediment transport, accelerates the potential pollution of surface water by organic waste and applied agrochemicals. Furthermore, compaction increases soil strenght and limits root elongation, leading to yield reduction of agricultural crops.

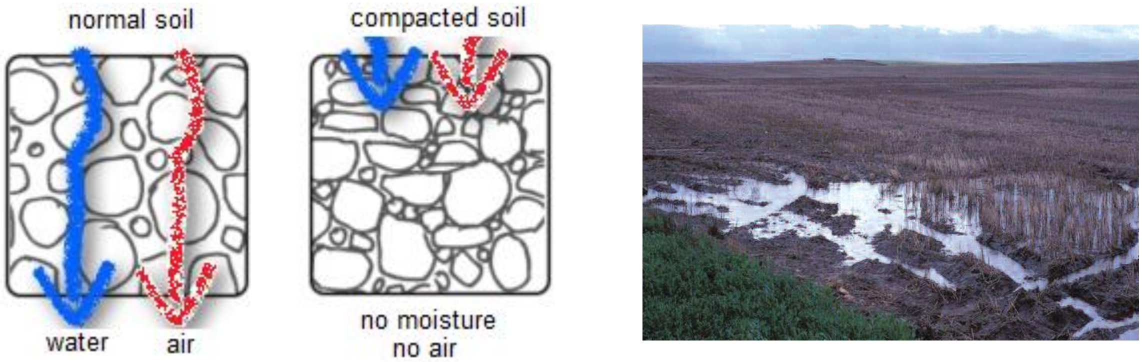

Fig. 1. Environmental effect of soil compaction: restricted water and air infiltration [24] and waterlogging in tracks from farm equipment [23]

Fig. 2. Agronomic effects of soil compaction: restricted root elongation [25] and visible compacted areas with poor plant emergence [22]

Estimates of yield loss due to soil compaction range from 5% to 50%. The increase in strength required for roots to penetrate compacted layers reduces root proliferation and thus, the soil volume they can explore. This limits the amount of water and nutrients that a plant can take up [26].

Topsoil compaction may occur naturally, by agricultural traffic, or by the formation of the ploughpan. In compacted soils, high mechanical resistance reduces root development and limits the absorbtion of water and nutrients by the plants [1]. Common indicators of soil compaction are bulk density and penetration resistance [7, 10, 13]. Penetration resistance is influenced by: soil moisture, bulk density, compressibility, texture, content of organic matter, total porosity [8, 17, 20], soil shear strenght and soil – metal friction [4]. Penetration resistance correlates positively with bulk density [8, 16], percentage of clay [6], wheel loading [13, 15], number of passes [12], and negatively with soil moisture [8, 15] and content of organic matter [8].

Experimental testing of penetration resistance is properly done if the soil is not dry or very wet, and best results are obtained if the tests are carried out in winter [14]. The critical value of penetration resistance, or the value from where the problems for crop development begin, varies between 1000-3500 kPa [3]. Crop development becomes difficult for penetration resistance above 2000 kPa [7]. At penetration resistance larger than 2500 kPa, root elongation is severely limited [21]. Penetration resistance measured by the penetrometer is usually 2 to 8 times higher than that actually undergone by root tips, due to the different way in which roots and penetrometer probes penetrate the soil [9].

In orchards, the traffic of machinery between tree rows, especially due to repeated sprayings with pesticides against diseases and pests during the year, may cause topsoil and subsoil compaction. Experiments conducted in a peach orchard, on a soil with high clay content, showed that at depths between 40-60 cm penetration resistances were higher than 2200 kPa, which decreased yields by 29.6% [2]. By measurements of penetration resistance, farmers can observe how soil compaction varies at different locations and propagates at different depths across the field and they can decide where to apply variable deep tillage, to benefit from increased timeliness and reduced management costs [18].

MATERIALS AND METHODS

Testswere carried out in November 2014, at the National Research - Development Institute for Machines and Installations Designed to Agriculture and Food Industry – INMA Bucharest, on three experimental plots: a plot of energy willow (*Salix Viminalis*), a cherry orchard and a plot of clover.

The characteristics of tested soil were determined [19]: in the upper 20 cm, the soil is loamy clay with glomerular rugged structure, medium and fine texture, moderately plastic and adhesive, with a density of 2.49 g/cm^3, bulk density of 1.22 g/cm^3 and total porosity of 51 %; at 20-35 cm deep, the soil is clayey loam, with angular glomerular structure and fine texture, is moderately compact, plastic and adhesive, with total porosity of 46 %; the layer between 35-80 cm is clayey loam, with medium prismatic structure and fine texture, is compact, plastic and adhesive, dry, with density of 2.69 g/cm^3, bulk density 1.75 g/cm^3 and total porosity 36 %.

Figure 3 shows the equipment used in the experiments. Penetration resistance was measured with the FieldScout SC 900 digital electronic cone penetrometer. Soil moisture was determined using the FieldScout TDR 300 capacitive portable moisture analyzer.

Fig. 3. FieldScout SC 900 penetrometer and FieldScout TDR 300 moisture analyzer

On the diagonal of each of the experimental plots were marked three points, found at 10 m distance from each other. Penetration resistance (P_r) was measured in each of the three points, in increments of 2.5 cm, to a total depth of 45 cm. In close vicinity (10 cm) of penetration measurements, moisture content was determined at four depths: 3.8; 7.5; 12 and 20 cm and the average value was computed. For each experimental plot were obtained three sets of values of penetration resistance, determined in each of the three marked points. Experimental data were interpreted based on the criteria in Table 1.

Table 1

Qualitative estimation of the degree of compaction by penetration resistance [19]

Soil compaction	Penetration resistance [kPa]
Low	< 1000
Average	1000 - 2000
Severe	2000 - 3000

RESULTS AND DISCUSSION

It should be mentioned that in the days before the experiments, poor rains fell and the water ponded in certain areas. On *the plot of energy willow*, soil moisture measured in the three marked points were: w_1 = 22.9 %, w_2 = 33.15 %, respectively w_3 = 35.25 %. The values of penetration resistance, at 0-45 cm depth, corresponding to the three moistures, are given in Table 2.

Table 2

Penetration resistance on the plot of energy willow

Soil depth [cm]	Pr_1 [kPa]	Pr_2 [kPa]	Pr_3 [kPa]
	w_1 = 22.9 %	w_2 = 33.15 %	w_3 = 35.25 %
0	245	350.5	421
2.5	386	456	544
5	491	526	900.5
7.5	526	737	1369
10	526	895	1386.5
12.5	702	1228.5	1333.5
15	877	1281.5	1298.5
17.5	1299	1298.5	1263.5
20	1790	1439	1298.5
22.5	1720	1562	1105.5
25	1509	1334	1316
27.5	1509	1597.5	1579.5
30	1755	2054	1930.5
32.5	1720	1966	2088.5
35	2703	2071.5	2071
37.5	2633	2211.5	1860
40	1931	2376	2597.5
42.5	1860	2547.5	2352
45	1790	2866	3194.5

It was plotted the variation of penetration resistance with soil depth, corresponding to the three values of soil moisture and presented in Fig. 4.

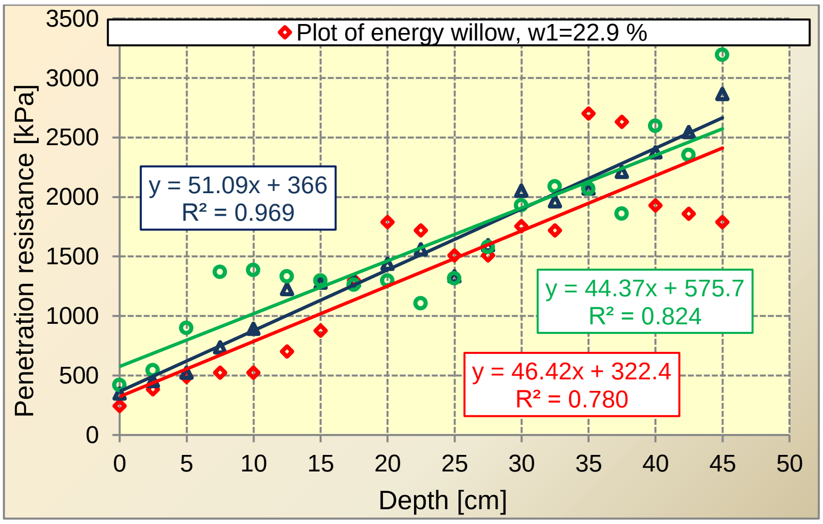

Fig. 4. Variation of penetration resistance on the plot of energy willow

To establish a correlation between penetration resistance and soil depth, it was used the regression analysis in Microsoft Office Excel program, by linear variation laws. For the plot of energy willow, the best correlation between penetration resistance and soil depth was achieved for w_2=33.15% with the correlation coefficient R^2 =0.969.

By comparing the values of penetration resistance obtained experimentally on the plot of energy willow with the data from Table 1, the following were observed:

a) at moisture content w_1 = 22.9 %: to a depth of 15 cm, soil is low compacted;

between 17.5 and 32.5 cm deep, soil has an average degree of compaction; at depths between 35 and 45 cm (normal plowing), the soil is severely compacted.

b) at moisture content w_2 = 33.15 %: to 10 cm deep, soil is low compacted; at depths between 12.5 and 27.5 cm, soil has an average degree of compaction; between 30 and 45 cm deep, the soil is severely compacted.

c) at moisture content w_3 = 35.25 %: to 5 cm deep, soil has a low degree of compaction; between 7.5 and 30 cm deep, soil has an average degree of compaction; at depths between 32.5 and 45 cm, the soil is severely compacted.

High values of penetration resistance, measured under the arable layer of the plot of energy willow, at depths of 45 cm (2866 kPa at w_2 = 33.15 %, respectively 3194.5 kPa at w_3 = 35.25 %) show that the wet soil is compacted, so water stalled at soil surface.

In the *cherry orchard*, measured values of soil moisture were: w_1 = 33.5 %, w_2 = 38.5 %, respectively w_3 = 44.8 %, and the values of penetration resistance corresponding to these moistures are presented in Table 3.

Table 3

Penetration resistance in the cherry orchard

Soil depth [cm]	Pr_1 [kPa]	Pr_2 [kPa]	Pr_3 [kPa]
	w_1 = 22.9 %	w_2 = 33.15 %	w_3 = 35.25 %
0	696	437	491
2.5	1299	1053	912
5	983	1228	1158
7.5	1004	1193	1088
10	1193	1334	1228
12.5	1439	1228	983
15	1753	1369	1123
17.5	1887	1315	1650
20	1902	1825	2057
22.5	1948	2001	1825
25	2115	1755	1580
27.5	2239	1825	1720
30	2344	2108	2036
32.5	2563	2203	2352
35	2282	2133	2001
37.5	2293	2071	2071
40	2352	2352	2212
42.5	2432	2422	2282
45	2984	2352	2212

Variation of penetration resistance with the depth of soil in the cherry orchard is presented in Fig. 5. Regression analysis showed that this variation follows a linear law of distribution. In the cheery orchard, the best correlation between penetration resistance and soil depth was achieved for w_2=38.5%, for which the correlation coefficient is R^2 =0.900.

By analyzing the values of penetration resistance obtained experimentally on the soil in the cherry orchard and by taking into account the data in Table 1, it was found that:

a) at moisture content w_1 = 33.5 %: to a depth of 5 cm the soil has a low degree of compaction; sudden increase in penetration resistance at 2.5 cm depth can be explained by the possibility that the penetrometer tip met a stone or a hard body during penetration; at depths between 7.5 and 22.5 cm the soil has an average degree of compaction, and at depths between 25 and 45 cm (shallow plowing) the soil is severely compacted.

b) at moisture content w_2 = 38.5 %: to 2.5 cm deep the soil is low compacted; an average degree of compaction is found between 5 and 27.5 cm deep; between 30 and 45 cm deep the soil is severely compacted.

c) at moisture content w_3 = 44.8 %: at 2.5 cm deep the soil has a low degree of compaction; at depths between 5 and 27.5 cm the soil has an average degree of compaction; at depths between 30 and 45 cm the soil is severely compacted.

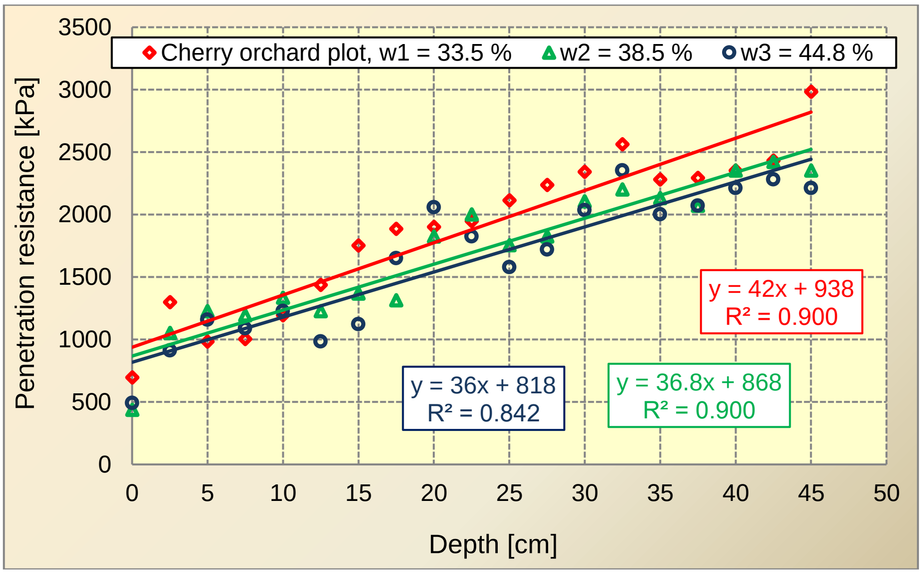

Fig. 5. Variation of penetration resistance with soil depth in the cherry orchard

Results of the experimental tests carried out on *the plot of clover* are presented in Table 4. The values of soil moisture were: w_1 = 29 %, w_2 = 37.7 % and w_3 = 36 %.

Based on these data, it was plotted graphically the variation of penetration resistance with the depth of soil on the plot of clover (Fig. 6). Regression analysis was used to establish the correlation between penetration resistance and soil depth, by linear variation laws. The best correlation was achieved for the plot with moisture w_3= 36%, with R^2 =0.937.

From the analysis of the values of penetration resistance measured on the plot of clover and based on the data presented in Table 1, the following were observed:

a) at moisture content w_1 = 29 %: down to the depth of 20 cm, the soil has a low degree of compaction; at depths of 22.5 and 25 cm, the soil has an average degree of compaction; the layer between 27.5 and 45 cm depth is severely compacted.

b) at moisture content w_2 = 37.7 %: at 10 cm deep, the soil has a low degree of compaction; between 12.5 and 35 cm deep, the soil is average compacted; at depths of 37.5 to 45 cm, the soil is severely compacted.

c) at moisture content w_3 = 36 %: down to 5 cm deep, the soil is low compacted; at depths ranging between 7.5 and 25 cm, the soil has an average degree of compaction; at depths between 27.5 and 45 cm, the soil is severely compacted.

Table 4

Penetration resistance on the plot of clover

Soil depth [cm]	Pr_1 [kPa]	Pr_2 [kPa]	Pr_3 [kPa]
	w_1 = 29 %	w_2 = 37.7 %	w_3 = 36 %
0	351	315.5	342
2.5	386	421	965
5	632	438.5	930
7.5	456	631.5	1070
10	737	842	1386.5
12.5	807	1141	1421.5
15	1053	1386	1439
17.5	948	1351.5	1649.5
20	983	1123.5	1421.5
22.5	1299	1141	1456.5
25	1544	1334	1667.5
27.5	2071	1667.5	2074
30	2247	1737.5	2141.5
32.5	2352	1807.5	2229.5
35	2457	1614.5	2299.5
37.5	2352	2106	2457.5
40	2141	2000.5	2391
42.5	2176	1895.5	2945.5
45	2071	2036	3069

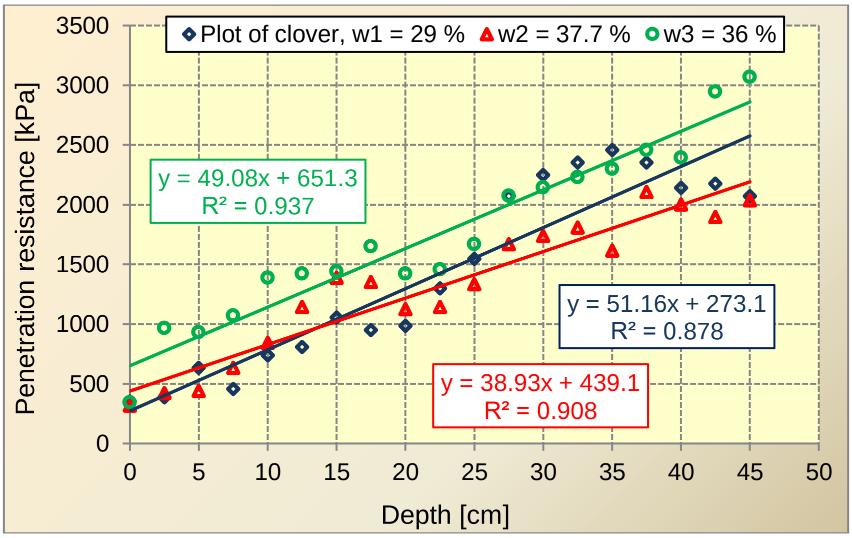

Fig. 6. Variation of penetration resistance with soil depth on the plot of clover

As it can be noticed from Figures 4-6, penetration resistance has linear variation with soil depth and it depends on the agricultural works conducted on the soil.

The three sets of experiments showed that regardless the agricultural use of tested soils and the treatments that were applied on these soils during the year, severely compacted layers of soil are found to a depth of 45 cm.

CONCLUSIONS

All agricultural works, from seedbed preparation to harvesting cause low or high compaction of soil.

Between 0 - 20 cm deep, penetration resistance has relatively small values, but they increase beyond this depth.

The hardpan is found at depths of 20 - 25 cm, depending on the agricultural works carried out on the plots, being mandatory to perform deep plowing or deep loosening of soil every 2 - 3 years. Sometimes, this depth increases up to values of 30 - 35 cm, where is observed a severe compaction, hence we can assume that plowing was performed under better conditions, but the weight of agricultural machinery has led to deep soil compaction.

Given that in the cherry orchard the values of penetration resistance indicated that the soil is severely compacted below 30 cm, it can be concluded that this is the depth to which fine roots of the trees (absorbing water and air) can develop normally.

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BIBLIOGRAPHY

1. **Adamchuck V.I., Skotnikov A.V., Speichinger J.D., Kocher M.F**., 2004 - *Development of an instrumented deep – tillage implement for sensing of soil mechanical resistance*. Transactions of the ASAE, vol. 47(6), pp. 1913-1919;
2. **Botta G**., 2000 - *Subsoil compaction distribution induced by agricultural traffic.* Thesis Doctor, Lujan University, Argentina;
3. **Da Silva R.V., Reichert J.M., Reinert D.J., Bortoluzzi E.C**., 2009 - *Soil water dynamics related to the degree of compaction of two Brazilian oxisols under no-tillage*. R. Bras. Ci. Solo., vol. 33, pp. 1097-1104;
4. **Dexter A.R.,Czyz E.A., Gate O.P**., 2007 - *A method for prediction of soil penetration resistance*. Soil & Tillage Research, vol. 93, pp. 412-419;
5. **Gabriels D., Cornelis W. M.** – *Human - induced land degradation*. Land use, land cover and soil sciences, vol. 3;
6. **Håkansson I.**, 2005 – *Machinery - induced compaction of arable soils. Incidence-consequences-counter-measures*. Swedish University of Agricultural Sciences, Department of Soil Sciences. Reports from the Division of Soil Management. No. 109;
7. **Hamza M.A., Anderson W.K**., 2005 - *Soil compaction in cropping systems. A review of the nature, causes and possible solutions*. Soil & Tillage Research, vol. 82, pp. 121-145;
8. **Johnson L.R., Page-Dumroese D., Han H.S**., 2007 - *Effects of machine traffic on the physical properties of ash-cap soils*. USDA Forest Service Proceedings RMRS-P-44, pp. 69-82;
9. **Lampurlanés J., Cantero-Martinez C**., 2003 - *Soil bulk density and penetration resistance under different tillage and crop management systems, and their relationship with barley root growth*. Agronomy Journal, vol. 95(3), pp. 526-536;
10. **Leung Y-F., Meyer K.**, 2003 - *Soil compaction as indicated by penetration resistance: a comparison of two types of penetrometers*. Tehcnology for Resource Management, pp. 370-375;
11. **Maheshwari D.K**., 2012 - *Bacteria in agrobiology: stress management*. Springer – Verlag Berlin Heidelberg;

12. **Mamman E., Ohu J. O**., 1998 - *The effect of tractor traffic on air permeability and millet production in a sandy loam soil in Nigeria*. Ife Journal of Technology, vol. 8(1), pp. 1-7;
13. **Mari G.R., Changying J**., 2008 - *Influence of agricultural machinery traffic on soil compaction patterns, root development, and plant growth, overview*. American-Eurasian Journal Agriculture & Environment Science, vol. 3(1), pp. 49-62;
14. **Molin J.P., Bashford L.L**., 1996 - *Penetration forces at different soil conditions for punches used on punch planters*. Transactions of the ASAE, vol. 39(2), pp. 423-429;
15. **Molnar A., Roș V., Drocaș I., Ranta O., Stănilă S., Marian O.**, 2009 - *Experimental researches regarding determination of soil cone index in a soil-tyre interaction process*. Bulletin UASVM Agriculture, vol. 66(1), pp. 400-405;
16. **Nawaz M.F., Bourrié G**., 2012 - *Soil compaction impact and modeling. A review*. Agronomy for Sustainable Development. Springerlink;
17. **Quraishi M.Z., Mouazen A.M**., 2013 - *Calibration of an on-line sensor for measurement of topsoil bulk density in all soil textures.* Soil & Tillage Research, vol. 126, pp. 219-228;
18. **Tekin Y., Kul B., Okursoy R**., 2008 - *Sensing and 3D mapping of soil compaction*. Sensors, vol. 8, pp. 3447-3459;
19. **Ungureanu N**., 2015 - *Contributions to the modeling of artificial compaction of agricultural soil*. Doctoral Thesis. University Politehnica of Bucharest, Romania;
20. **Vaz M.P.C., Manieri M.J., de Maria C.I., Tuller M**., 2011 - *Modeling and correction of soil penetration resistance for varying soil water content*. Geoderma, vol. 166, pp. 92-101;
21. **Whalley W.R., To J., Kay B.D., Whitmore A.P**., 2007 - *Prediction of the penetrometer resistance of soils with models with few parameters*. Geoderma, vol. 137, pp. 370-377.
22. *Don't ignore soil compaction* (http://www.agupdate.com/crops/don-t-ignore-soil-compaction/article_d6eb8622-4319-5e41-ab92-4f737bf5dc0f.html)
23. *Managing wet soils* (http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/soil-and-land/soil-and-water/managing-wet-soils/?id=1195497988026)
24. *Nurture the soil* (http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=20001)
25. *Principles of Non-Inversion Tillage* (http://paxtonplow.com/.cm4all/stcfb/000000032451.html)
26. https://agrilife.org/texasrowcrops/2015/11/04/wet-weather-field-traffic-more-soil-compaction-reduced-nutrient-use-efficiency-and-yield/