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Analysis of Greenhouse Soils by Means of Aqueous Extracts

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1. Introduction

Practically all laboratories engaged in routine testing of greenhouse soils employ one or another water extraction technique. The aqueous extracts are primarily used to determine the salinity level of the soils by means of measuring the electrical conductivity. Some applied extraction methods are those employing 1 : 2 and 1 : 5 soil : water suspensions. During the last few years use has also been made of saturation extracts, the extracts being obtained from soil samples that are saturated with water in a certain standardized manner [*Richards et al., 4*].

The Research Station at Naaldwijk for many years has used the 1 : 5 extraction method. For characterization of the salinity levels of Dutch greenhouse soils, both the electrical conductivity and the chloride content are determined in the extracts. The latter determination is included because of the high chloride contents of Dutch greenhouse soils. These high contents are caused by the high chloride level of the irrigation water used. In the extracts, some important nutrients, like nitrate, phosphate, and potassium are also determined. It has been found that the 1 : 5 extracts are quite suitable for assessing the nitrate-, phosphate-, and potassium levels of greenhouse soils.

The 1 : 5 extract has the advantage that it can be easily obtained from widely different greenhouse soils, also from those with high moisture-holding capacities, like peat soils. The method, however, also has some disadvantages. The most important of these are:

1. Data on electrical conductivity and chloride-, nitrate-, and potassium levels have to be interpreted in dependence of the moisture-holding capacities of the soils.

2. The electrical conductivity of the 1 : 5 extract of a soil containing gypsum gives a too unfavourable impression of the salinity level. This results from the low soil : water ratio of the 1 : 5 suspension causing the sparingly soluble gypsum to dissolve in relatively large quantities.

According to reports in the literature [*Drews, 1*], [*McNaught* and *Houston, 3*], [*Richards et al., 4*], [*Winsor et al., 5*], the above disadvantages are of little consequence in saturation extracts due to the low ratio of the moisture content of a saturated soil to that of the soil at field capacity. Furthermore, this ratio seems to vary little from soil to soil. For these reasons, the Research Station at Naaldwijk some years ago conducted an investigation to test if the presently used 1 : 5 extraction method could not better be replaced by a method making use of a saturation extract. In this investigation, the chemical compositions of 1 : 5 extracts and saturation extracts obtained from 75 soils were compared with those of extracts obtained with an hydraulic press from field-moist samples. The solution obtained by means of pressing will be called press extract. In this article, a part of the results obtained will be reported for the first time.

Table 1. The average contents of organic matter, clay, and carbonate and the average pH values of sampled soil types (15 samples per soil type)

	Organic matter %	Clay particles (particles < 2 mu) %	Carbonate (as $CaCO_3$) %	pH 1:5 suspension
Sand	5.9	3.7	0.3	6.6
Loam	5.9	11.3	2.2	7.0
Clay	10.3	22.8	2.4	7.1
Peaty clay	17.9	26.5	0.7	6.4
Peat	26.9	23.3	0.4	6.4

2. *Materials and Methods*

2.1 Soil samples

The investigation was conducted with soil samples taken from 75 greenhouses used for tomato growing. The following soil types were equally represented: sand, loam, clay, peaty clay, and peat. In table 1, some characteristics of these soils are presented.

In each greenhouse, the following samples were taken:

1. One large sample of approximately 25 dm^3 from the 5–30 cm layer.
2. Three core samples of undisturbed soils from the 15–20 cm layer. The cores had an inner diameter of 5 cm and a volume of 100 cm^3.

The investigations were carried out almost entirely on soil from the large samples. The core samples were used only to determine moisture contents at pF 1.8.

2.2 Drying the soil samples

A portion of each of the large samples was dried overnight at 50° C, ground, and stored for several months. The soil thus treated will be called air-dry soil.

2.3 Extracts

The press extracts were obtained from field-moist samples with an hydraulic press. The volume of soil used in the press was large enough to contain 400 ml of moisture. Of each soil, 50 ml of press extract were collected.

Saturation extracts were obtained from both field-moist and air-dry samples. Saturation of the soil took place in a manner described by *Richards et al.* [*4*]. The saturated samples were stored overnight at 25° C, after which they were transferred to a filter and subjected to 0.5 atm suction. The extracts thus collected from field-moist and air-dry samples will be called saturation extracts (field-moist) and saturation extracts (air-dry), respectively.

The 1 : 5 extracts were obtained from air-dry samples. The moisture present in these air-dry samples was taken into account when adding water. The suspensions were shaken for 15 minutes and stored overnight at 25° C. The next morning, they were again shaken for 15 minutes and run through a filter.

In the 1 : 5 extracts and the saturation extracts (air-dry), low nitrate contents were found as a result of denitrification. Therefore, for nitrate determinations, other 1 : 5 suspensions and saturated portions were prepared which were filtered after two hours instead of after one night.

The nitrate contents of saturation extracts (field-moist) appeared to be unaffected by denitrification.

2.4 *Measurements made in the extracts*

In the extracts the following measurements were made:

electrical conductivity	mmho/cm (25° C)	measured at 25° C
osmotic pressure	atm (0° C)	measured cryoscopically (freezing-point depression)
potassium	me/1	flame-photometrically
chloride	me/1	titrimetrically (mercuri-nitrate method)
sulphate	me/1	gravimetrically
nitrate	me/1	colorimetrically (phenol-disulfonic-acid method)
phosphate	mg P_2O_5/1	colorimetrically (molybdenum-blue method, metol as reducing agent)

2.5 *pF 1.8*

The core samples were adjusted to pF 1.8 (moisture tension –63 cm H_2O) with the aid of the so-called sand-box method described by *Van der Harst* and *Stakman* [2].

2.6 *Moisture determination*

Moisture contents of the field-moist, saturated, and air-dry samples were determined by weighing the samples before and after drying in an oven at 105° C. Moisture contents at pF 1.8 were determined by drying and weighing the core samples.

Moisture contents are expressed in grams of moisture per 100 grams of oven-dry soil.

2.7 Other determinations

The following determinations were made on air-dry samples:

organic matter	loss-on-ignition method
clay (particles $<$2 mu)	pipette method of Robinson
carbonate (as $CaCO_3$)	Scheibler method
pH	1 : 5 suspension

For the organic-matter determination, air-dry samples were first dried at 105° C and next ignited at 600° C. No correction was made for moisture lost during ignition.

The organic-matter, clay, and carbonate contents are expressed in per cents of oven-dry soil.

3. Results

3.1 Moisture contents

A summary of the moisture contents found is given in table 2. Moisture contents of field-moist samples were approximately equal to moisture contents at pF 1.8. The correlation between both moisture contents is high ($r = 0.987$). The pF values of the soils at sampling time were therefore low and showed littled variation from soil to soil. This was to be expected, since in The Netherlands greenhouse soils are watered regularly. The soils are kept nearly at field capacity.

Moisture contents of saturated soils (field-moist) were higher than those of saturated soils (air-dry). The differences were on the average 20 per cent. Thus, it makes a difference whether field-moist or dried samples are used for preparing saturation extracts.

Moisture contents of saturated samples (field-moist) were closely correlated with moisture contents of field-moist samples. In figure 1, the relationship between both moisture contents is given. The relationship between moisture contents of saturated samples (air-dry) and those of field-moist samples showed a similar picture.

Table 2. The average moisture contents of field-moist samples, saturated samples, and samples at pF 1.8 of five soil types (contents in grams of moisture per 100 grams of oven-dry soil)

	Moisture content field-moist soil	Moisture content at pF 1.8	Moisture content saturated soil (field-moist)	Moisture content saturated soil (air-dry)
Sand	27.5	27.2	49.0	42.4
Loam	25.2	25.5	44.5	39.1
Clay	39.3	39.1	71.8	59.8
Peaty clay	61.1	60.2	99.6	82.2
Peat	80.4	77.0	117.8	96.7

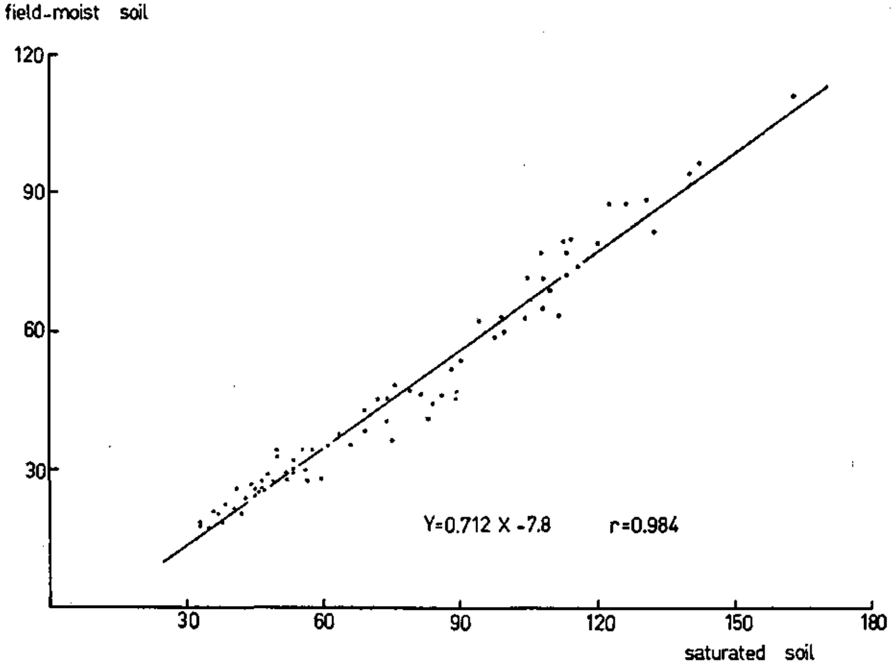

Figure 1. The relationship between the moisture content of saturated soil (field-moist) and the moisture content of field-moist soil (contents in grams of moisture per 100 grams of oven-dry soil).

The ratio '*moisture content saturated soil (field-moist)/moisture content field-moist soil*' varied between soil types. The ratios were 1.8, 1.6, and 1.5 for mineral, peaty-clay, and peat soils, respectively. The ratio varied also within one soil type, especially for sandy soils (extreme values 1.4 and 2.1). The dilution of the soil moisture occuring when field-moist samples are saturated, varied thus from soil to soil.

3.2 Moisture content and organic matter

Moisture contents of field-moist samples were closely correlated with organic-matter contents. The two values plotted for the various soils show a linear relationship. The regression equation is:

$Y = 2.617X + 11.8 \qquad r = 0.985$ (I)

in which: Y = moisture content of field-moist soil, X = organic-matter content

The correlation coefficient is high. Therefore, organic-matter contents of Dutch greenhouse soils, as determined by loss-on-ignition, can be used to obtain estimates of moisture contents at field capacity.

In this investigation, equation (I) is used to convert electrical conductivity and chloride-, nitrate-, and potassium contents of the 1 : 5 extracts to those of field-moist soils. The conversion was therefore not based on actual moisture content of field-moist soil but on moisture content estimated with the aid of equation (I) from the organic-matter content. This was done so because the organic-matter content of a soil is easily determined and relatively constant. The latter cannot be said of the moisture content of a field-moist soil. In periods during which little water is applied, for instance towards the end of a growing season, moisture contents of greenhouse soils can drop markedly. Furthermore, during the customary leaching of the soil after a growing season, the moisture content may be higher than at field capacity.

The moisture content calculated from equation (I) will be termed V.

3.3 Osmotic pressure and electrical conductivity

The values for osmotic pressure and for electrical conductivity of press extracts, saturation extracts, and 1 : 5 extracts, respectively, were highly correlated. The regression equations calculated were:

press extracts	$Y = 0.349X - 0.19$	$r = 0.987$
saturation extracts (field-moist)	$Y = 0.325X - 0.08$	$r = 0.981$
saturation extracts (air-dry)	$Y = 0.327X - 0.09$	$r = 0.967$
1 : 5 extracts	$Y = 0.245X - 0.00$	$r = 0.954$

in which: Y = osmotic pressure in atm (0° C)
X = electrical conductivity in mmho/cm (25° C)

The correlation coefficients are high. With the equations found, the osmotic pressures of the various extracts can therefore with reasonable accuracy be calculated from the electrical conductivity. The regression coefficients decrease in value in the order press extracts, saturation extracts (air-dry), saturation extracts (field-moist), 1 : 5 extracts. This order is that of decreasing soil: water ratios; it is probably associated with changes in chemical composition of the soil moisture.

3.4 Press extracts and soil solution

To test if the press extract forms a useful approximation of the soil solution, some additional investigations were made. These investigations and the results obtained were:

1. The osmotic pressures of the soil solutions were determined by measuring the freezing-point depressions in field-moist soils. They turned out to be practically similar to the osmotic pressures of the press extracts.

2. Of 15 of the field-moist soil samples, two aliquots of the press extracts were obtained and analyzed. The two aliquots, both 50 ml, were collected from 400 ml of soil moisture. The electrical conductivities and the chloride-, nitrate-, and potassium contents of both aliquots were practically similar. The phosphate contents of both aliquots, however, varied relatively widely. The first and second aliquots contained on the average 6.9 and 4.7 mg P_2O_5/1, respectively.

From these results, the conclusion can be drawn that the electrical conductivity and the chloride-, nitrate-, and potassium contents of the press extract of a soil agree well with those of the soil solution. This can probably not be said of the phosphate content.

Table 3. Results of analyses made on the extracts

	Press extracts		Saturation extracts (field-moist)		Saturation extracts (air-dry)		1 : 5 extracts	
	mean	range	mean	range	mean	range	mean	range
Electrical conductivity[1]	6.7	3.4–10.8	4.4	2.2– 6.7	4.6	2.3– 6.6	0.9	0.4– 1.8
Potassium[2]	6.4	2.1–17.4	4.9	0.9–13.3	4.3	1.1–13.6	1.1	0.2– 2.5
Chloride[2]	16.2	5.9–37.1	8.2	3.0–20.5	9.7	3.6–24.4	1.2	0.2– 3.5
Nitrate[2]	20.7	2.9–44.8	12.1	1.4–27.1	14.1	2.6–28.9	1.7	0.2– 5.5
Phosphate[3]	6.4	0.4–33.1	15.0	2.4–53.4	11.3	1.6–34.4	11.2	2.1–37.6

[1] mmho/cm (25°C) [2] me/1 [3] mg P_2O_5/1

3.5 *Comparison of the chemical compositions of the extracts*

A summary of the results of analyses performed on the extracts is given in table 3. The average values for chemical composition of the various extracts differed rather widely. In the 1 : 5 extracts, for instance, more potassium and much more phosphate were found than in the press- and saturation extracts. The chloride- and nitrate contents of the 1 : 5 extracts were, however, relatively low (negative adsorption).

Table 4. Coefficients of correlation between analytic results obtained on press extracts, on the one hand, and those obtained on saturation extracts and on 1 : 5 extracts adjusted to soil-moisture level, on the other hand

	Press extracts and saturation extracts (field-moist)	Press extracts and saturation extracts (air-dry)	Press extracts and 1 : 5 extracts[1]
Electrical conductivity	0.890	0.845	0.752
Potassium	0.965	0.936	0.927
Chloride	0.957	0.927	0.965
Nitrate	0.931	0.909	0.940

[1] analytic results adjusted to soil-moisture level

The potassium-, chloride-, and nitrate contents of the saturation extracts were closely correlated with the corresponding contents of the press extracts. The correlations were poorer for the electrical conductivity values. The correlation coefficients are presented in table 4. For the saturation extracts (field-moist), they are somewhat higher than for the saturation extracts (air-dry).

The potassium-, chloride-, and nitrate contents of the 1 : 5 extracts, after adjustment to soil-moisture levels (multiplying by $\frac{500}{V}$), were also closely correlated with the corresponding contents of the press extracts (Table 4). The correlation between electrical conductivity of the 1 : 5 extracts, adjusted to soil-moisture level, and the electrical conductivity of the press extracts was much poorer.

The regression equations for the saturation extracts (field-moist) and the 1 : 5 extracts are listed in table 5. The regression equations obtained for the saturation extracts (air-dry) agreed closely with those for the saturation extracts (field-moist).

Table 5. Regression equations for the relationships between analytic results obtained on press extracts, on the one hand, and those obtained on saturation extracts (field-moist) and on 1 : 5 extracts adjusted to soil-moisture level, on the other hand

	Regression equations	
Electrical conductivity	$Y = 0.619X + 0.2$	$Z = 1.921X - 2.3$
Potassium	$Y = 0.705X + 0.4$	$Z = 1.740X + 1.7$
Chloride	$Y = 0.526X - 0.3$	$Z = 0.795X + 0.3$
Nitrate	$Y = 0.556X + 0.6$	$Z = 0.957X - 1.1$

X = analytic results of press extracts
Y = analytic results of saturation extracts (field-moist)
Z = analytic results of 1 : 5 extracts, after adjustment to soil-moisture level

The poorer correlation between values for electrical conductivity of the 1 : 5 extracts, adjusted to soil-moisture level, and those of the press extracts is probably caused primarily by varying quantities of gypsum dissolved in 1 : 5 suspensions due to variations in gypsum contents of the soils examined. For this reason, a multiple correlation was calculated for values of (a) electrical conductivity of the 1 : 5 extracts, adjusted to soil-moisture level, (b) electrical conductivity of the press extracts, and (c) sulphate content of the 1 : 5 extracts. Since the influence of sulphate will increase with increasing values of the ratio '*moisture content of 1 : 5 suspension/moisture content at field capacity*', the sulphate contents of the 1 : 5 extracts were adjusted to soil-moisture level. The regression equation found was:

$Y = 0.962X + 0.0722Z - 0.3 \qquad R = 0.936$

in which:

Y = electrical conductivity of 1 : 5 extracts, adjusted to soil-moisture level
X = electrical conductivity of press extracts
Z = sulphate content of 1 : 5 extracts, adjusted to soil-moisture level

The correlation coefficient is high. Thus, for a proper interpretation of the electrical conductivity of 1 : 5 extracts, it is necessary to know the sulphate content.

It was mentioned before, that the press extract probably does not supply a good estimate of the quantity of phosphate in the soil moisture. It is likely that

the phosphate contents of the press extracts were in most cases considerably lower than those of the soil solutions. The correlation coefficients for the relationships between phosphate contents of the press extracts, on the one hand, and phosphate contents of each of the saturation- and 1 : 5 extracts, on the other hand, were:
0.826 saturation extracts (field-moist)
0.791 saturation extracts (air-dry)
0.738 1 : 5 extracts

The average phosphate content of the 1 : 5 extracts was practically equal to that of the saturation extracts (air-dry). A relatively close correlation ($r = 0.879$) existed between the values of these two phosphate contents. The phosphate contents of the saturation extracts (field-moist) were also relatively closely correlated with those of the 1 : 5 extracts ($r = 0.890$).

4. *Summary and Conclusion*

An investigation was made to test if the saturation extract is to be preferred to the 1 : 5 extract for the chemical analysis of Dutch greenhouse soils.

The moisture content of the sampled soils was practically similar to that at pF 1.8.

The chemical composition of both the 1 : 5 extract and the saturation extract was compared with the composition of the solution obtained from field-moist soil with the aid of an hydraulic press. The electrical conductivity and the potassium-, chloride-, and nitrate contents of the latter solution agreed closely with those of the soil solution. This was probably not the case with the phosphate content.

The electrical conductivity and the potassium-, chloride-, and nitrate contents of the soil solution could be satisfactorily estimated with both the saturation- and 1 : 5 extracts. When adjusting the potassium-, chloride-, and nitrate contents of the 1 : 5 extracts to the corresponding contents of the soil solution, the moisture content of the field-moist soil had to be taken into account. Aside from this adjustment, the electrical conductivity of the 1 : 5 extracts had to be corrected for the sulphate content as well.

The moisture content of the field-moist soil could be derived very well from the organic-matter content (determined by loss-on-ignition method).

The phosphate contents of the 1 : 5 extracts were approximately equal to those of the saturation extracts. Comparison of these phosphate contents with those of the solutions obtained with the hydraulic press was not meaningful. The phosphate contents of the latter solutions were on the average considerably lower than those of the soil solution.

The conclusion can be drawn that the saturation extract does not yield any important advantages over the 1 : 5 extract for the determination of salt-, nitrate-, phosphate-, and potassium levels of Dutch greenhouse soils. A possible disadvantage of the use of the 1 : 5 extract is that organic matter and sulphate have to be determined, but this disadvantage is small compared with the difficulties associated with making a saturation extract for routine soil-testing purposes.

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