© Suoseura — Finnish Peatland Society
Helsinki 1997

ISSN 0039-5471
Suo 48(2): 43–49

Relationship between electrical conductivity and water content in peat growth medium

Turpeen puristenesteen sähkönjohtavuuden riippuvuus vesipitoisuudesta

Risto Rikala & Juha Heiskanen

Risto Rikala & Juha Heiskanen, The Finnish Forest Research Institute, Suonenjoki Research Station, FIN-77600 Suonenjoki, Finland (e-mail risto.rikala@metla.fi)

The relationship between electrical conductivity (EC) of press-water extract and water content (WC) of peat growth medium at desorption was studied. A simple time-domain reflectometer (TDR), traditional laboratory conductivity meter and gravimetric weighing were used to measure EC and WC. The relationship between EC values measured with a laboratory conductivity meter from press-water extract and those measured with TDR directly from peat medium was curvilinear. The relationship between WC of peat measured with TDR and that determined gravimetrically, although nearly linear, was slightly sigmoidal. Empirical curve between EC values and WC values measured with TDR was close to the theoretical curve, which was calculated on the basis of increase in ion concentration at desorption. Transformed EC values of press-water extract were higher than the theoretically calculated values. For comparison of EC values measured from press-water extracts in various water contents, transforming coefficients were derived.

Key words: fertilization, nutrient monitoring, TDR

INTRODUCTION

The soil solution that surrounds the root system of plants is crucial for growth and is thus one of the most critical factors to be monitored when tree seedlings are cultured (Landis 1989). Mineral nutrients present in the solution are indicated by the total salt concentration, which in turn is proportional to the electrical conductivity (EC) of the solution. In horticulture and in nurseries where tree seedlings are grown in containers, EC is widely used for monitoring the nutrient level of growth media.

The EC of a growth-medium solution can be monitored by several methods. The procedure for extracting saturated medium is one of the most common and recommended methods (Bunt 1988, Landis 1989). This consists of adding enough distilled water to a sample of growth medium to reach the saturation point; and after it is allowed to equilibrate for 1.5 h, the solution is extracted with a vacuum filter (Warncke 1986). In Finland, however, to avoid saturation and vacuum-extraction, the growth-medium solution is normally squeezed physically from peat medium at the actual water content (WC) *in situ* (Puustjärvi 1979). In order to compare the EC values of the press-water extract in different samples, the samples should be taken from media that have the same WC. Therefore it is recommended that samples of peat should contain optimum water content, 45–50% (VV^{-1}) (Viljavuustutkimuksen ... 1996). However, this is not always possible (e.g. because of rain). Therefore, for comparison of EC values, they should first be transformed to correspond to the EC value at a certain fixed WC.

In container culturing, the WC of peat medium has traditionally been estimated gravimetrically by weighing the mass of the seedling tray (Rikala 1985, Landis 1989), but so far the EC-transforming coefficients have been determined for only a relatively narrow range of WC (Puustjärvi 1979). In recent years, by using time-domain reflectometry (TDR), the WC (e.g. Topp et al. 1984, Paquet et al. 1993) and the EC (e.g. Dalton et al. 1984, van Loon et al. 1990) of soil can be measured simultaneously. TDR cannot, however, be used in container tree nurseries because, so far, the probes have been too large to be inserted into small containers.

The aim of this study was to determine how EC measured from press-water extract depends on the WC in peat at desorption. This relationship was estimated by using a simple TDR instrument, which was calibrated against EC values for press-water extract measured with a laboratory conductivity meter and against WC values measured gravimetrically. Furthermore, transforming coefficients were estimated for comparison of EC values measured from press-water extracts taken from peat with various water contents.

MATERIAL AND METHODS

Experiment 1

In Experiment 1 (Expt. 1) two methods, conductivity meter and TDR, were compared in order to ascertain how well they measured EC from growth medium. EC was measured: 1) from the press-water extract of peat samples with a conductivity meter (CDM80, Radiometer, Denmark, accuracy ± 0.35% of reading) using temperature calibration to 25°C, and 2) directly from peat medium with a simple TDR instrument. According to the manufacturer (Rockwool TFDL Watergehaltemeter, Rockwool/Grodan BV, The Netherlands), the measurement range of the TDR-instrument was 5 to 100% ($V V^{-1}$) for WC with an accuracy of 3% ($V V^{-1}$) and 0 to 5 mS cm^{-1} for EC with an accuracy of ± 0.2 mS cm^{-1}. TDR measurements are based on noncontinuous, transient values measured after insertion of a 3-rod TDR probe. The rods, 65 mm long, were in a line, with a distance of 25 mm between rods.

The peat medium used in this study, was low-humified *Sphagnum*-peat growth medium (Tree seedling peat, E, Vapo Corp., Finland; for properties, see Heiskanen 1993). Five-litre buckets with drainage holes in the bottom were filled with peat, which was first watered with deionized water to a WC of 70% ($V V^{-1}$). After this basic watering, in order to create different EC levels in the peat, the peat samples in the buckets were soaked with six different concentrations of fertilizer solution (EC of solution in parenthesis): 0.0% (0.01 mS cm^{-1}), 0.1% (1.05 mS cm^{-1}), 0.2% (2.0 mS cm^{-1}), 0.4% (3.7 mS cm^{-1}), 0.6% (5.1 mS cm^{-1}), 0.8% (6.5 mS cm^{-1}). Two buckets were saturated from above with each solution and extra water was allowed to drain out through holes in the bottom. The fertilizer used in the solutions was Superex 9 (Kekkilä Corp., Finland) with mineral nutrient concentrations of 19.4% N, 5.3% P, 20% K and micronutrients.

One day after soaking, the lids were removed from the buckets and the contents were allowed to dry gradually by evaporation. The EC and WC of samples were measured with TDR three times during the drying period of eight days. From each bucket, EC and WC were measured with TDR twice before and twice after a peat sample was taken for press-water extract. The peat in the bucket was mixed before the sample (200 ml) was taken. The press-water sample was extracted from peat by a hydraulic squeezer with a pressure of 981 kPa. During the drying period, the temperature in the buckets varied from 17.9 to 21.0°C and the WC of the peat from 88 to 59% ($V V^{-1}$). The pH of the press-water, measured with a pH-meter (Jenway 3020, Jenway Ltd, England), varied from 5.1 to 6.4.

Experiment 2

In Experiment 2 (Expt. 2) gravimetry and TDR were compared as ways of measuring WC of peat growth medium. Two plastic buckets (5 l) with drainage holes in the bottom were filled with low-humified *Sphagnum*-peat growth medium (Finnpeat M6, Kekkilä Corp., Finland; for properties, see Heiskanen 1993). The peat was thoroughly watered with deionized water and allowed to soak overnight in buckets with lids. The lids were then removed and the peat was allowed to dry gradually by evaporation.

During drying, the mass of the buckets was weighed, and the WC (%, V V^{-1}) and EC (mS cm^{-1}) of peat were measured three times a week using TDR. For TDR measurements, the mean of three successive measurements was used. The volumes of the peat in the buckets were estimated at the beginning of the experiment. After the first drying cycle, the peat in the buckets was remixed and rewatered and was monitored in the same way as in the first cycle. The first drying cycle lasted about 5 weeks and the second cycle about 10 weeks. During the first and second monitoring cycle, the WC of peat decreased from 70 to 16% (V V^{-1}) and from 92 to 10% (V V^{-1}), respectively. After the second cycle, the dry mass of the peat of both buckets was weighed after drying at 105°C to constant mass. WC was then estimated by the gravimetric method using the formula: (wet mass–dry mass)*(initial wet volume)$^{-1}$.

EC values measured from peat medium with TDR in Expt. 2 were transformed by the equation from Expt. 1 to correspond to the EC values in press-water extract. Both the transformed EC values (estimating EC in press-water extract) and the original EC values measured with TDR were plotted against the gravimetrically measured WC of peat during drying. On the basis of the curve for press-water extract, equations were derived for transforming EC values measured from press-water extract at an actual WC to EC values at the optimum WC (46% V V^{-1}) or at saturation (95%, V V^{-1}).

RESULTS

In Expt. 1, the relationship between EC values measured with a conductivity meter from press-water extract and those measured with TDR directly from peat medium was curvilinear (Fig. 1). Above an EC value of 1.3 mS cm^{-1}, TDR gave lower values than measurement of EC in the press-water extract did; below 1.3 mS cm^{-1}, TDR gave comparatively higher values.

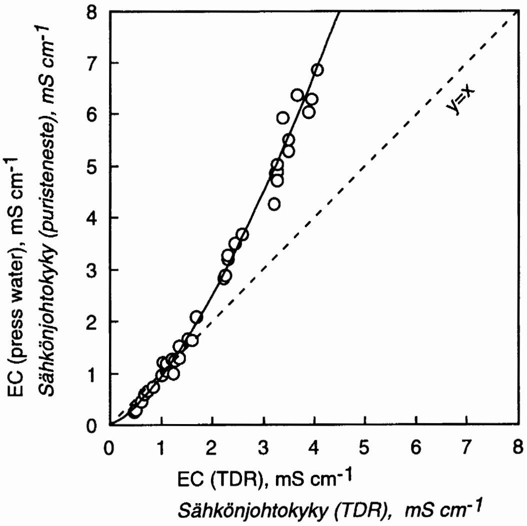

Fig. 1. EC measured from press-water extract with a laboratory conductivity meter as a function of EC measured from bulk peat medium with TDR in Expt. 1. The WC of peat varied from 88 to 59% (V V^{-1}) during the measurement period. Each dot is the mean of four measurements with TDR and one measurement from the sample of press-water extract. Observations were smoothed with the least-square power-curve fit $y = 0.947x^{1.401}$ ($N = 36$, $R^2 = 0.996$, RMSE $= 0.22$).

Kuva 1. Turpeen puristenesteen sähkönjohtokyky TDR:llä mitatun sähkönjohtokyvyn funktiona kokeessa 1. Turpeen vesipitoisuus vaihteli mittauksen aikana 88:sta 59 tilavuus-%:iin. TDR:llä mitatut EC arvot ovat neljän mittauksen keskiarvoja ja puristenesteestä mitattu yhdestä puristenestenäytteestä mitattu arvo. Tasoituskäyrä on muotoa $y = 0.947x^{1.401}$ *(*$N = 36$, $R^2 = 0.996$, *RMSE* $= 0.22$*).*

In Expt. 2, while peat dried from near saturation (92%, V V^{-1}) to a WC of 10% (V V^{-1}), the relationship between the WC values measured with TDR and those determined gravimetrically was slightly sigmoidal, as estimated by the third order polynomial (Fig. 2). Within the range 40–80%, TDR slightly overestimated the WC compared with gravimetrically determined WC, which was partly due to shrinking of the peat volume.

The values measured with TDR and smoothed with power-curve fitting was close to the theoretical curve, which was calculated on the basis of the increase in ion concentration during the decrease of WC by evaporation (Fig. 3). The trans-

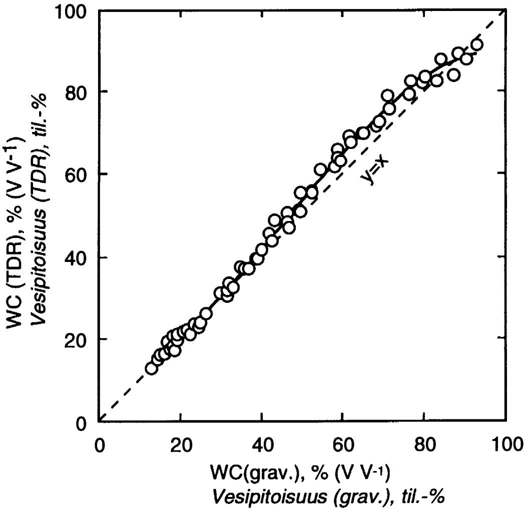

Fig. 2. Water content of light *Sphagnum*-peat medium measured by TDR as a function of volumetric water content determined by weighing in Expt. 2. Each dot represents the mean of three successive TDR measurements and one weighing value. The fitted curve illustrates the least square fit to the third-order polynomial $y = -0.00014x^3 + 0.01934x^2 + 0.30367x + 7.4857$ ($N = 63$, $R^2 = 0.999$, RMSE $= 1.53$).

Kuva 2. TDR:llä mitattu vaalean rahkaturpeen vesipitoisuus punnitsemalla mitatun vesipitoisuuden funktiona kokeessa 2. Yksi piste edustaa kolmea TDR-mittausta ja yhtä punnitusarvoa mittausajankohtaa kohti. Tasoituskäyrä on kolmannen asteen polynomi $y = -0.00014x^3 + 0.01934x^2 + 0.30367x + 7.4857$ *(*$N = 63$*,* $R^2 = 0.999$*, RMSE = 1.53).*

formed EC values increased more steeply than did the theoretically estimated values at desorption.

The coefficients derived for transforming EC values measured from press-water extract at an actual WC to EC value at the optimum WC or at saturation are presented in Fig. 4.

DISCUSSION

The discrepancy in EC values measured by TDR and conductivity meter (Fig. 1) did not depend much on the WC of peat in the range WC 60–90% (V V^{-1}), since within that range only a slight change in EC in relation to WC was found (Fig. 3, Expt. 2). Measured directly from solutions with different salt concentrations, TDR and the conductivity meter gave similar EC values (data not shown). In previous studies, the relationships between EC values of coarse silty soil (Dalton et al. 1984) and sandy and loam soils (van Loon et al. 1990) measured by TDR and the EC of extracted soil water (measured by standard conductivity bridge) were linear; and all slopes were nearly one. However, as Nadler (1997) notes, WC and surfaces of solids modify the EC of the soil solution by varying the amount, composition and activity of dissolved ions and soil tortuosity. Especially in clay, a disagreement can be found between EC in bulk soil and that in soil solution. Here, the organic peat medium also showed a discrepancy between EC estimates obtained by TDR from bulk peat and by conductivity meter from press-water extracts. Peat is known to have colloidical properties which modify the ionic activity of peat at desorption (Kwak et al. 1986) and this could partly explain the discrepancy.

The relationship between the WC of peat measured with TDR and that determined gravimetrically was slightly sigmoidal (Fig. 2). Empirical relationships between the apparent dielectric number and the volumetric WC are also commonly described by third-order polynomials (Topp et al. 1980, Paquet et al. 1993, Myllys & Simojoki 1996). The instrument used in this study is normally used to measure the WC of rockwool growth medium. Obviously, in this instrument the built-in system of calibration for transforming the measured apparent dielectric number to the value for WC output is not completely accurate for peat growth medium. Consequently, in this study, the relationship between output values and gravimetrically measured values for WC remained slightly sigmoidal. However, this is of no practical importance in monitoring the WC of growth medium in nurseries.

EC values measured with TDR increased in peat medium at desorption similarly to the values calculated theoretically according to increase in concentration (Fig. 3). EC values transformed to correspond to the EC values in press-water extract increased faster at desorption than the calculated values did. The transformed values were, however, considered to be more feasible for nursery use, since all the present recommendations are given for aqueous extracts. The reason for the difference between transformed values and calculated values in dry peat, like in clay (Nadler 1997), is obviously due to the physico-chemical

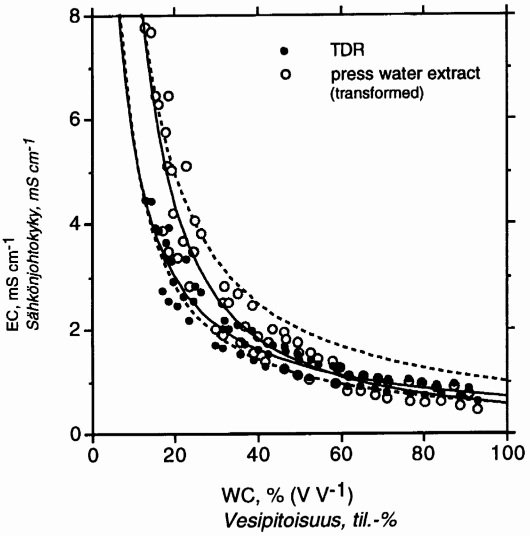

Fig. 3. EC measured with TDR and the same values transformed (equation from Fig. 1) to correspond to EC of press-water extract as a function of the gravimetrically measured water content of peat medium during drying. Observations were smoothed with least-square power-curve fits TDR: $y = 45.4x^{-0.905}$ (N = 63, $R^2 = 0.984$, RMSE = 0.27) and EC of press-water extract: $y = 201.5x^{-1.269}$ (N = 63, $R^2 = 0.971$, RMSE = 0.51). Dash lines show the theoretical dependence between EC and WC. The lower one represents the peat studied (Expt. 2) with EC = 0.56 mS cm^{-1} and the upper one represents peat with a stronger nutrient level (EC = 1,0 mS cm^{-1}) at WC 95% (V V^{-1}).

Kuva 3. Turpeen kuivuessa TDR:llä mitattu johtokyky (•) ja Kuvassa 1 annetulla yhtälöllä TDR:n johtokyvystä puristenesteen johtokyvyksi muunnetut arvot (o) gravimetrisesti määritetyn turpeen vesipitoisuuden funktiona. TDR:n tasoituskäyrä on muotoa $y = 45.4x^{-0.905}$ (N = 63, $R^2 = 0.984$, RMSE = 0.27) ja puristenesteen johtokyvyn tasoituskäyrä muotoa $y = 201.5x^{-1.269}$ (N = 63, $R^2 = 0.971$, RMSE = 0.51). Katkoviivat kuvaavat laskettua, teoreettista johtokyvyn ja vesipitoisuuden riippuvuutta. Alempi vastaa tutkitun turpeen (Koe 2) ravinnetasoa (johtokyky = 0.56 mS cm^{-1} vesipitoisuudessa 95 til-%) ja ylempi voimakkaampaa ravinnetasoa (johtokyky = 1.0 mS cm^{-1} vesipitoisuudessa 95 til-%).

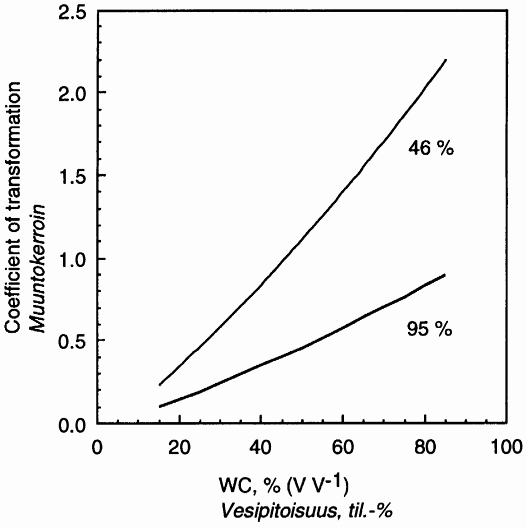

Fig. 4. Coefficient curves for transforming EC values measured from water extract pressed from peat medium at actual water content to EC values at optimum water content (46%) and at saturation (95%). The equations for the curves are $y = 0.00752x^{1.2775}$ and $y = 0.003306x^{1.2775}$ for water content of 46% and saturation (95%), respectively. For example, if the actual volumetric water content in peat medium is 40%, the EC value measured from the extract squeezed from peat has to be multiplied by $0.003306 * 40^{1.2775} = 0.37$ to estimate the EC value of extract taken at saturation.

Kuva 4. Muuntokäyrät johtokykyarvojen muuntamiseksi turpeen vallitsevasta kosteudessa mitatuista vastaamaan optimaalista kasvatuskosteutta (46%) ja kyllästysvesipitoisuutta (95%). Käyrien yhtälöt ovat muotoa $y = 0.00752x^{1.2775}$ (46%) ja $y = 0.003306x^{1.2775}$ (95%). Esimerkiksi jos turpeen kosteus on 40%, on puristenesteestä mitattu arvo kerrottava 0.37:lla ($0,003306 * 40^{1.2775}$), jotta saataisiin arvo vastaamaan saman turpeen kyllästyskosteudessa olevaa turpeen johtokykyä.

properties of peat medium as discussed above. Our results, however, seem to contradict those of Puustjärvi (1979), who showed that the EC of press-water decreased more slowly at sorption than did the theoretically calculated values in solution. He suggested that the decrease in EC with dilution was due to an increase in the activity of ions and to an increase in the solubility of weakly soluble salts.

In container nursery practice, the EC recommendations for peat growth medium are usually given for extracts taken at one fixed WC, e.g. saturation. By using the equations presented here, EC can be monitored in practice at actual WC and still be assessed with the EC recommendations given for fixed (46 and 95%) WC values. Thereby, the use of EC values measured from extract squeezed from peat media at a known WC *in situ* makes it easy to estimate both the total nutrient level of peat in seedling culturing and the effect of salinity on the availability of water to the seedling.

REFERENCES

Bunt, A. C. 1988. Media and mixes for container-grown plants. 2nd ed. Unwin Hyman, London. 309 pp.

Dalton, F. N., Herkelrath, W. N., Rawlins, D. S. & Rhoades, J. D. 1984. Time-domain reflectometry: Simultaneous measurement of soil water content and electrical conductivity with single probe. Science 224: 989–990.

Heiskanen, J. 1993. Variation in water retention characteristics of peat growth media used in tree nurseries. Silva Fennica 27: 77–97.

Kwak, J. C., Ayub, A. L. & Sheppard, J. D. 1986. The role of colloid science in peat dewatering: Principles and dewatering studies. In: Fuchsman, C. H. (ed.). Peat and Water, pp. 95–118. Elsevier Applied Science Publishers Ltd., London.

Landis, T. D. 1989. Mineral nutrients and fertilization. In: Landis, T. D., Tinus, R. W., MacDonald, S. E. & Barnett, J. P. (eds.). The container tree nursery manual, Vol. 4. Agriculture handbook 674, pp. 1–67. U.S. Department of Agriculture, Forest Service, Washington DC.

Myllys, M. & Simojoki, A. 1996. Calibration of time domain reflectometry (TDR) for soil moisture measurements in cultivated peat soils. Suo 47: 1–6.

Nadler, A. 1997. Discrepancies between soil solute concentration estimates obtained by TDR and aqueous extracts. Australian Journal of Soil Research 35: 527–537.

Paquet, J. M., Caron, J. & Banton, O. 1993. In situ determination of the water desorption characteristics of peat substrates. Canadian Journal of Soil Science 73: 329–339.

Puustjärvi, V. 1979. The effect of fertilizers on the electrical conductance of peat extract. Peat Research Institute. Peat & Plant Yearbook 1979: 27–40.

Rikala, R. 1985. Paakkutaimien kastelutarpeen määrittäminen haihdunnan perusteella. Summary: Estimating the water requirements on the basis of evapotranspiration. Folia Forestalia 627: 1–18.

Topp, G. C., Davis, J. L. & Annan, A. P. 1980. Electromagnetic determination of soil water content: Measurements in coaxial transmission lines. Water Resources Research 16: 574–582.

Topp, G. C., Davis, J. L., Bailey, W. G. & Zebchuk, W. D. 1984. The measurement of soil water content using a portable TDR hand probe. Canadian Journal of Soil Science 64: 313–321.

van Loon, W. K. P., Perfect, E., Groenevelt, P. H. & Kay, B. D. 1990. A new method to measure bulk electrical conductivity in soils with time domain reflectometry. Canadian Journal of Soil Science 70: 403–410.

Viljavuustutkimuksen tulkinta metsätaimitarhoilla. 1996. Viljavuuspalvelu Oy. 18 pp.

Warncke, D. D.1986. Analyzing greenhouse growth media by the saturation extraction method. HortScience 21: 223–225.

TIIVISTELMÄ:

Turvekasvualustan sähkönjohtavuuden ja vesipitoisuuden riippuvuus mitattuna TDR-käsimittarilla

Tutkimuksessa selvitettiin kivivillan vesipitoisuuden mittaamiseen tarkoitetun, TDR-käsimittarin (Grodan, Hollanti) käyttöä turpeen vesipitoisuuden ja sähkönjohtokyvyn mittaamisessa. Tavoitteena oli tutkia turpeen puristenesteen sähkönjohtokyvyn riippuvuutta turpeen vesipitoisuudesta.

Ensimmäisessä kokeessa (Koe 1) täytettiin viiden litran astiat lannoitetulla turpeella (Metsätaimiturve E, Vapo Oy) ja näitä turpeita kasteltiin kyllästyskosteuteen kuudella eri pitoisuuden omaavalla lannoiteliuoksella. Turpeiden vähitellen kuivuessa mitattiin niiden sähkönjohtokykyä TDR-mittarilla suoraan turpeesta ja laboratoriojohtokykymittarilla saman turpeen puristenesteestä kolme kertaa 8 vuorokauden aikana. Turpeen puristenesteestä mitatun ja suoraan turpeesta TDR:llä mitatun sähkönjohtokyvyn riippuvuus oli epälineaarinen (Kuva 1). Kun johtokyky oli alle 1,3 mS cm^{-1}, oli TDR:llä mitattu johtokyky korkeampi kuin puristenesteestä mitattu johtokyky ja vastaavasti johtokyvyn ollessa yli 1,3 mS cm^{-1}, TDR osoitti puristenesteestä mitattuja arvoja alhaisempia lukemia.

Toisessa kokeessa (Koe 2) seurattiin TDR-mittarilla peruslannoitetun, puhtaalla vedellä kastellun turpeen (Finnpeat M6, Kekkilä Oy) sähkönjohtokyvyn ja vesipitoisuuden muutosta turpeen kuivuessa kyllästetystä turpeesta (95 tilavuus-%) noin 20 tilavuus-%:n vesipitoisuuteen. Samalla turpeen vesipitoisuutta seurattiin gravimetrisesti. Gravimetrisesti ja TDR:llä mitatut turpeen vesipitoisuusarvot vastasivat hyvin toisiaan, riippuvuus oli lähes lineaarinen (Kuva 2).

TDR:llä kokeessa 2 mitatut turpeen johtokykyarvot muunnettiin kokeesta 1 saadulla yhtälöllä (Kuva 1) puristenesteen johtokyvyksi. Sekä näiden puristenesteen johtokyvyksi muunnettujen arvojen että alkuperäisten, TDR:llä mitattuja arvojen riippuvuus turpeen vesipitoisuudesta esitetään Kuvassa 3. TDR:llä mitatut vesipitoisuudet vastaavat varsin hyvin teoreettisia arvoja, jotka on laskettu olettamalla ravinnemäärän pysyvän samansuuruisena vesipitoisuuden vähetessä. Sen sijaan puristenesteen johtokyvyksi muunnetut arvot kasvoivat laskennallisia arvoja nopeammin turpeen kuivuessa. Näiden puristenestearvojen arvioitiin kuitenkin vastaavan paremmin tilannetta kasvien kannalta turpeessa. Turpeen vesipitoisuuden ja puristenesteen johtokykykäyrän yhtälöstä laskettiin muuntoyhtälöt, joilla voidaan tunnetun vesipitoisuuden omaavan turpeen puristenesteen johtokykyarvo muuntaa vastaamaan joko optimikasvatuskosteutta (46 til.-%) tai kyllästyskosteutta (95 til.-%) vastaavaa johtokykyä (Kuva 4).

Received 13.5.1997, accepted 4.9.1997