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The Occurrence of Soil Water Repellency in the North & South Islands Under Pasture

Infiltration of water into soil is affected by various factors such as compaction, water repellency and surface sealing, which may enhance run-off. Soil water repellency, or hydrophobicity causes many environmental problems including, for example, flooding, accelerated soil erosion, nutrient leaching, pollution of water ways, and reduced groundwater recharge (Müller & Deurer, 2011). It can also reduce pasture growth. Soil water repellency (SWR) is generally caused by organic compounds derived from living or decomposing plants or microorganisms. Many researchers reported that soil factors such as soil organic matter (SOM) content, soil temperature and soil texture; climatic factors and different land uses influence SWR.

Deurer et al. (2011) conducted a survey on the occurrence of SWR in the top 4 cm of soils across 50 sites (ten major soil orders x five drought proneness classes) under dry-land pasture in the North Island. They highlighted the importance of SWR for New Zealand pastoral production systems and found that 98% of the sites became hydrophobic when they dried out, and that 70% of the sites were hydrophobic at field moisture level. We have extended and designed a survey to investigate the relevance of SWR in pastoral topsoils in the South Island of New Zealand. This paper combines the results of both surveys and analyzes how various soil and climatic factors influence the occurrence of SWR under pastoral land use in New Zealand.

Materials and Methods

We conducted a survey on the occurrence of SWR in the top 4 cm of surface soils across New Zealand. Our hypothesis was that SWR is dependent on soil order and that it is correlated to the drought proneness of topsoils plus the summer rainfall in humid temperate regions. We selected 76 pastoral sites (Figure 1) by combining these three criteria. We selected eleven dominant soil orders of New Zealand soil classification under pastoral land use; Podzol, Organic, Recent, Pumice, Ultic, Gley, Brown, Pallic, Granular, Allophanic and Semi-arid.

We then stratified our sampling within the soil orders by a drought proneness factor, and annual summer rainfall.

To ensure accessibility of the sampling sites, we selected only polygons that are intersected by State highways or rural roads. For availability of sites under pasture, we selected only large polygons intersected by high producing pasture as specified in Land Cover Database II.

The field sampling for the SWR survey was conducted in December-January 2009/2010 for the North Island, and for the South Island the samples were collected in January 2012.

In the laboratory, the thatch (~1 cm) was cut off and discarded. We collected 4 cm of the topmost layer of mineral soil, and the soil was then sieved through a 2-mm sieve. The degree of SWR was quantified by using the Molarity of Ethanol Droplet test (MED). One half of the field-fresh subsample was directly used to derive the actual persistence of SWR using the WDPT test (WDPT$_{act}$). The other half was dried at 65ºC for 48 h before measuring the WDPT to derive the potential persistence of SWR (WDPT$_{pot}$).

In order to understand more fully other soil factors that are possibly related to SWR, additionally bulk density, pH, and SOM content were measured. A subsample of ~20 g was used for soil organic carbon (SOC) and soil organic nitrogen (SON) analysis.

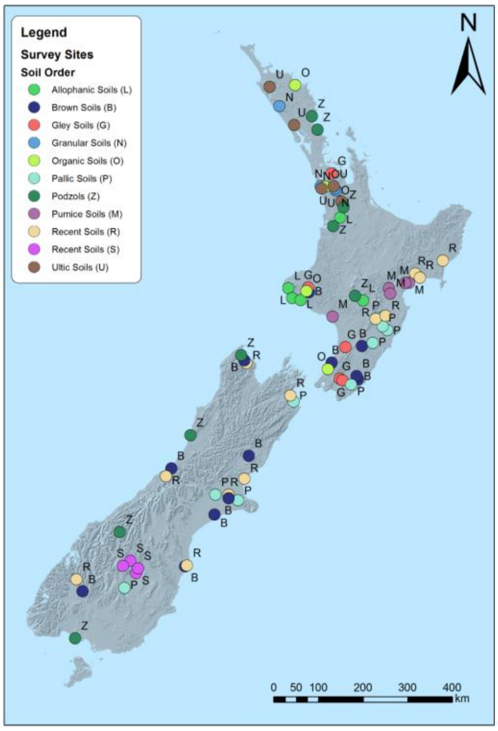

Figure 1: The final 76 sampling sites of the survey on the occurrence of soil water repellency in New Zealand considering eleven soil orders and three classes of each drought proneness and summer rainfall. State highways and rural roads were considered in the selection of sampling sites for easy accessibility.

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Results and discussion

The measurement of the WDPT test indicated that 47 out of 76 sites (62%) of the field fresh top-soil samples (volumetric soil moisture varied from 7 to 75%) were hydrophobic at the time of sampling. The topsoils of 67 of the 76 pastoral sites (=88%) showed the potential to become hydrophobic if they were dried at 65ºC. Nine of the sites of the survey had a contact angle below 90°, the threshold for hydrophobicity, and thus, were not hydrophobic. According to the SWR ranking scheme introduced by Dekker & Jungerius (1990), the SWR of the air-dried samples was on average extremely persistent (Table 1). However, we found that the North Island soils were more prone to SWR than the South Island soils. Both potential persistence (P=0.012) and degree (P=0.007) of SWR were significantly higher in the North Island than the South Island.

Table 1: Overview of survey results. The soil properties of 76 sites (eleven soil orders x three drought proneness classes x three summer rainfall classes) were sampled in the top 4 cm of the soil under pastoral land use across New Zealand. Nine of the 76 sites were not hydrophobic (contact angle <90°) and were excluded from the calculation of the statistics for the contact angle.

Soil property	Mean	Median	CV (%)	Min.-Max
Contact angle (°)	96.8	97	3.9	90.4–104.1
WDPTpot (s)	1493.9	284.4	171.8	0.2-11880
WDPTact (s)	835.3	14.8	253	0-9948
SWR class[1] of field fresh samples (-)	3	1	119	0-9
SWR class[1] of air-dried samples (-)	4	3	72	0-9
Soil moisture (Vol.%)	33.6	32.5	41.5	7.1-74.9
Carbon (%)	8.9	7.5	73.1	2.6-40.6
Nitrogen (%)	0.8	0.7	54.9	0.3-2.9
C/N ratio (-)	10.8	10.3	14.7	8.3-16.5
pH(KCl) (-)	5	4.9	9.8	4.0-6.1
Bulk density (g cm^{-3})	1	1	25.4	0.5-1.5

[1] *The SWR classes are: 0 – wettable; 1 – slightly persistent (5-60 seconds); 2 – moderately persistent (60-600 seconds); 3 – severely persistent (600-3600 seconds); 4 – extremely persistent (>1 hour). Class 4 is further subdivided into 5 – 3-6 hours; 6 - > 6 hours (Dekker & Jungerius, 1990)*

Impact of soil order, drought proneness and summer rainfall on the degree of SWR

The drought proneness did not show any significant effect on the degree of SWR (P=0.052). However, summer rainfall appeared to influence the presence of hydrophobicity (P=0.004), especially at high rainfall rates (>350 mm). Soil order did not have a significant influence on the degree of SWR (P=0.06). In general the degree of SWR was greatest for the soil orders Podzol and Organic, followed by Recent, and was least for the soil orders Allophanic and Pallic (Figure 2). Therefore, we hypothesized that 'Podzol' Soils are the most vulnerable for SWR among New Zealand soil orders under pastoral land use. The SOC content of this soil was the highest (14.6±9.4%) and the soil had the lowest bulk density (0.8±0.2 g cm^{-3}) among the soils tested. Therefore, the accumulation of hydrophobic organic matter coatings on the surface of soil minerals may have increased the degree of SWR.

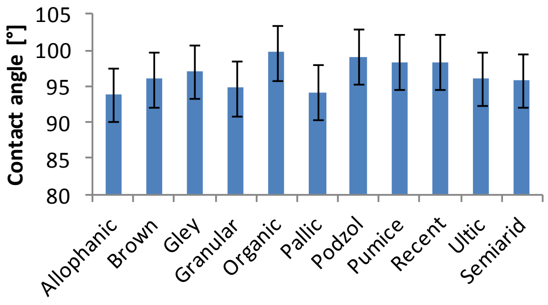

Figure 2: The degree of SWR of samples measured as contact angle with the molarity of ethanol droplet test from the top 4 cm of the soils covering eleven soil orders. The sites which had a contact angle of <90° (not potentially hydrophobic) were excluded from the analysis. The bars denote one standard error.

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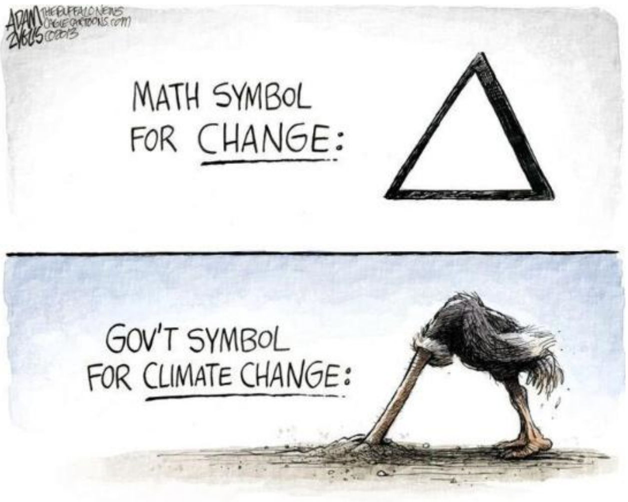
The Change Agent

This **WISPAS** we honour as our *Professional* - The Change Agent. The IPCC are, hopefully, agents of real change after the recent release of their Assessment Report 5 on *Impacts, Adaptation and Vulnerability*. (see the article on the back page)



Downer ... But Not Out

Climate change is as rich with opportunity as it is with danger. One of the things that made it so difficult for individuals and countries to be serious about climate is that the agenda is such a downer.

If climate change is a total downer because everything looks so serious, and the only ways to cope effectively are to give up all good things in life, it's going to be really hard to take action.

If dealing effectively is taking an innovative, creative, entrepreneurial approach, building great businesses and communities, then it's a problem that we can deal with.

Chris Field
Lead author, *Climate Change 2014*
IPCC

Rotten

The main message we want to get out there is that climate change is caused by the rotten economic system.

Vivienne Westwood
English fashion designer

Low Lister

There are plenty of problems in the world, and doubtless climate change - or whatever the currently voguish phrase for it all is - certainly is one of them. But it's low on my list.

P. J. O'Rourke
American political satirist & journalist

We found a significant positive relationship between the degree and the potential persistence of SWR (R=0.88, P<0.0001) (Figure 3). Thus, we could use the degree of SWR for analyzing potential correlations with other soil properties such as soil organic carbon, pH and soil particle distribution, instead of using the potential persistence of SWR, which has a high spatial variability and uncertainty in the measurements, especially if the persistence is high. Following Deurer et al. (2011), we also examined the 'critical contact angle', that is the contact angle above which the SWR can be expected to be at least moderately persistent (WDPT > 60 seconds). We found a critical contact angle of 93.6° for the entire survey (Figure 3). Deurer et al. (2011) found the critical contact angle was 93.8° for the North Island survey. These results also further demonstrate the reliability of the measurement of the contact angle for indirectly deriving the persistence of SWR. In addition, the measurement procedure of the contact angle (MED test) is faster than the measurement of the persistence of SWR (WDPT test). Thus, the critical contact angle might serve as a relatively quick and cost-effective measure for the likelihood that SWR leads to economic and environmental impacts under pastoral land-use (Deurer et al., 2011).

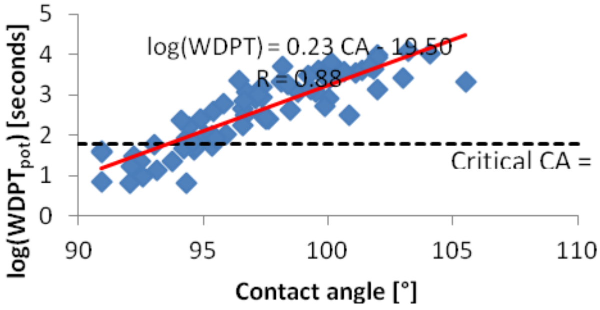


Figure 3: The persistence of SWR (log WDPT_{pot}) as a function of the degree of SWR (contact angle, CA) of 67 of the total 76 sites of the survey. Soil samples were taken with five replicates per site from the top 4 cm of the soils. Nine sites of the survey with a contact angle <90° (not potentially hydrophobic) were excluded from the analysis. The dashed line shows the log WDPT_{pot} threshold of being moderately persistent (= WDPT_{pot} of 60 seconds). The critical contact angle is 93.6° (intersect between the dashed line and the regression line).

A set of simple correlation analyses between various general soil properties including pH, bulk density and SOC content, and the degree of SWR (contact angle) and the persistence of SWR (log(WDPT_{pot}) and log(WDPT_{act})) was performed. The nine sites of the survey with soils of a contact angle <90° (not potentially hydrophobic) were excluded from the correlation analysis between the contact angle and various general soil properties. All other correlations were performed with the entire dataset. The resulting correlation matrix with correlation coefficient values (R) is shown in Table 2.

Table 2: Matrix with the correlation coefficients (R) of measured soil properties. The values describe the correlation of selected soil properties from the top 4 cm of the soils in New Zealand. The soil samples which had a contact angle of <90° (not potentially hydrophobic) were excluded from the analysis.

	Log WDPT_{act}	Log WDPT_{pot}	Soil water content	Bulk density	Organic carbon	Nitrogen	pH
Contact angle	0.41*	0.88*	-0.15	-0.50*	0.49*	0.47*	-0.05
Log WDPT_{act}		0.42	-0.55*	-0.18	0.23	0.20	-0.15
Log WDPT_{pot}			-0.13	-0.39	0.34	0.33	-0.03
Soil water content				-0.11	-0.04	0.03	-0.09
Bulk density					-0.71	-0.75	0.14
Organic carbon						0.97	-0.10
Nitrogen							-0.11

* P<0.001

The correlation analysis indicated that the degree of SWR was positively correlated with the soil SOC (R=0.49) and SON (R=0.47) contents, and negatively (R=-0.5) with bulk density. The pH values ranged from 4.0 to 6.1 and did not significantly (R=0.05) correlate with the contact angle. The persistence of SWR for field-fresh samples was negatively correlated with the soil water content (R=-0.55) (Table 2).

If we use 60 seconds as the threshold for SWR being moderately persistent, we find that moderately persistent SWR only occurred for volumetric water contents below 47% (Figure 4).

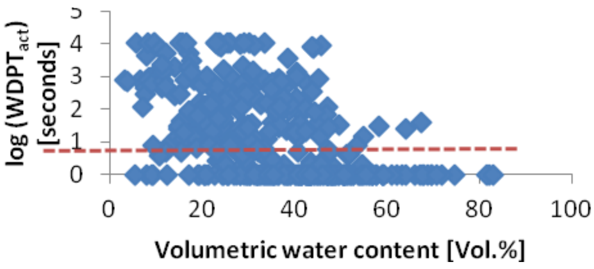


Figure 4: The actual persistence of SWR as a function of the volumetric water content. Samples above the dashed line have at least a moderately persistent SWR, and this occurs at critical volumetric water content below 47%. The samples were taken from the top 4 cm of 76 sites across eleven soil orders, three drought proneness and three summer rainfall classes. Within each site five samples were taken.

Conclusion

We conducted a survey on the occurrence of SWR in the top 4 cm of soils under pastoral land use at seventy-six sites, across New Zealand. Our sampling sites represented the combination of eleven major soil orders, three drought proneness factors and three summer rainfall classes. The top-soils of 67 out of 76 pastoral sites (=88%) showed the potential to become hydrophobic if they dried out, and 62% of the field fresh top-soils were hydrophobic at the time of sampling in summer. Our survey confirms that SWR occurs in a wide range of soils. Podzol Soils were the most vulnerable soil orders to SWR among New Zealand major soil orders under pastoral land use. Our results contribute to the knowledge of which soil parameters affect SWR, and therefore may be useful in predicting its occurrence and severity in dry pastoral farm lands in New Zealand.

Acknowledgements

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In: WISPAS 117 (March 2014)

A simplification of the Mualem - Van Genuchten relation between conductivity and pressure head

Introduction

Probably the most frequently employed equations describing hydraulic properties of soil are those developed by Mualem (1976) and Van Genuchten (1980). These are flexible but relatively complicated. The goal of this note is to derive a simplification of an important part of the relation between conductivity and pressure head. The simplification results in faster computations and moreover the approximation can be used to compute the matric flux potential in a simple way.

Derivation of the simplification

The relation between conductivity and pressure head according to the Mualem (1976) – Van Genuchten (1980) is given by

$$k = k_s \frac{\left(\left(|\alpha h|^n + 1 \right)^{\frac{n-1}{n}} - |\alpha h|^{n-1} \right)^2}{\left(|\alpha h|^n + 1 \right)^{(2+\lambda)\frac{n-1}{n}}} \qquad (1)$$

where k is the hydraulic conductivity (cm d^{-1}), k_s is k at saturation (cm d^{-1}), h is the pressure head (cm), and α (cm^{-1}), λ and n are parameters.

We write Eq. (1) in the form

$$y = \frac{k}{k_s} = \left(|\alpha h|^n + 1 \right)^{-m\lambda} \left(|\alpha h|^n + 1 \right)^{-2m} \left(\left(|\alpha h|^n + 1 \right)^m - |\alpha h|^{\frac{m}{1-m}} \right)^2 \qquad (2)$$

where y is the relative hydraulic conductivity and $m = (n - 1)/n$.

To cast Eq. (2) in a simpler form first we substitute $s = 1 + |\alpha h|^n$ or $|\alpha h| = (s - 1)^{1/n}$ and we obtain

$$y = s^{-m\lambda} s^{-2m} s^{2m} \left(1 - \left(\frac{s-1}{s} \right)^m \right)^2 = s^{-m\lambda} \left(1 - \left(\frac{s-1}{s} \right)^m \right)^2 \qquad (3)$$

Note that s is related to the effective degree of saturation S_e (= (θ-θ_r)/(θ_s-θ_r)) as $s = S_e^{-1/m}$.

If we now define a new variable x as

$$x = \frac{s-1}{s} = \frac{|\alpha h|^n}{|\alpha h|^n + 1} \qquad (4)$$

with inverse $s = 1/(1-x)$ we find

$$v = (1-x)^{\lambda m} (1-x^m)^2 \qquad (5)$$

From the definition of x (Eq. (4)) it follows that $0 \le x < 1$ since $s \ge 1$. If we write x^m as a Taylor series around $x = 1$, it can be given by

$$x^m = 1 + m(x-1) + O(x-1)^2 \qquad (6)$$

Therefore it follows that

$$(1-x^m)^2 \approx (1-(1+m(x-1)))^2 = (-m(x-1))^2 = m^2(1-x)^2 \qquad (7)$$

Substitution of Eq. (7) into Eq. (5) results in

$$y = s^{-\lambda m} \left(1 - 2\left(\frac{s-1}{s} \right)^m + \left(\frac{s-1}{s} \right)^{2m} \right) = (1-x)^{m\lambda} (1-x^m)^2 \approx m^2 (1-x)^{2+m\lambda} \qquad (8)$$

Now (1 – x) can be approximated as

$$1 - x = 1 - \frac{|\alpha h|^n}{|\alpha h|^n + 1} = \frac{1}{|\alpha h|^n + 1} \approx |\alpha h|^{-n} \qquad (9)$$

For h sufficiently large, the $k(h)$ relation can be approximated by a power function

$$k = k_s m^2 |\alpha h|^{-(2+m\lambda)n} \qquad (10)$$

This means that there is a linear relationship between ln(k) and ln(h) according to

$$\ln(k) = \ln\left(k_s m^2 \alpha^{-2n-(n-1)\lambda} \right) - (2n - (n-1)\lambda) \ln|h| \qquad (11)$$

with the intercept given by ln($k_s m^2 \alpha^{-2n-(n-1)\lambda}$) and the slope by ($2n$ - (n - 1)λ).

A power type function for $k(h)$ was proposed by Wind (1955) and later by Brook and Corey (1964), and here it is shown that for large absolute values of h the Mualem – Van Genuchten $k(h)$ relationship approaches such a power type function.

In the derivations above two approximations have been applied, one for the function x^m and one for the function (1 – x). The question now is for what range of h-values such approximations are justified. First a choice should be made as to what deviation, relative to the exact value, is maximally acceptable, let this deviation be denoted by ε ($\varepsilon > 0$).

In case of the first function the requirement is then (cf. Eq. (6))

$$\left| \frac{x^m - (1 + m(x-1))}{x^m} \right| = \frac{(1 + m(x-1)) - x^m}{x^m} \le \varepsilon \qquad (12)$$

The minimum acceptable value of x is thus found by solving

$$-(1+\varepsilon)x^m + mx - m + 1 = 0 \qquad (13)$$

for $x = x_c$. Then because of Eq. (4) we find the requirement for acceptable values of h as

$$h \le h_{c,1} = -\frac{1}{\alpha} \left(\frac{x_c}{1 - x_c} \right)^{\frac{1}{n}} \qquad (14)$$

The second value for h_c ($h_{c,2}$) is found by requiring that the relative difference

$$\frac{\left| \frac{1}{|\alpha h|^n + 1} - \frac{1}{|\alpha h|^n} \right|}{\frac{1}{|\alpha h|^n + 1}} = \frac{|\alpha h|^n + 1}{|\alpha h|^n} - \frac{|\alpha h|^n + 1}{|\alpha h|^n + 1} = \frac{1}{|\alpha h|^n} \le \varepsilon \qquad (15)$$

This results in

$$|h| \ge \frac{1}{\alpha} \varepsilon^{-\frac{1}{n}} \rightarrow h \le h_{c,2} = -\frac{1}{\alpha} \varepsilon^{-\frac{1}{n}} \qquad (16)$$

For a chosen value of ε, the most strict value for h_c would be taken as the minimum of $h_{c,1}$ (Eq. (14)) and $h_{c,2}$ (Eq. (16))

$$h_c \le \min\left[-\frac{1}{\alpha} \left(\frac{x_c}{1 - x_c} \right)^{\frac{1}{n}}, -\frac{1}{\alpha} \varepsilon^{-\frac{1}{n}} \right] \qquad (17)$$

A more relaxed requirement would be to take the average of $h_{c,1}$ (Eq. (14)) and $h_{c,2}$ (Eq. (16)).

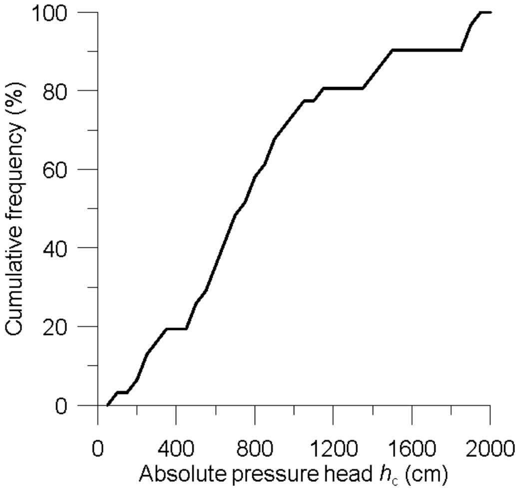

Figure 1. Cumulative frequency of the critical absolute value of the critical pressure head h_c at $\varepsilon = 0.05$.

Application

To check the above findings the database Staring Series (Wösten et al., 2001) that gives data for 32 Dutch soil types was used. For each soil type first the upper value of the pressure head was calculated with Eq. (17). Figure 1 gives the cumulative frequency distribution of the absolute value of the upper value of *h*. The lower value of *h* was taken as -5000 cm. Within this interval 50 equidistant values of the pressure head were calculated and with Eq. (1) 50 corresponding values of the soil conductivity. Then a linear regression was applied to obtain the slope and intercept of this relation, these are compared with the slope and intercept of Eq. (11) in Fig. 2 and Fig. 3. The agreement is quite good.

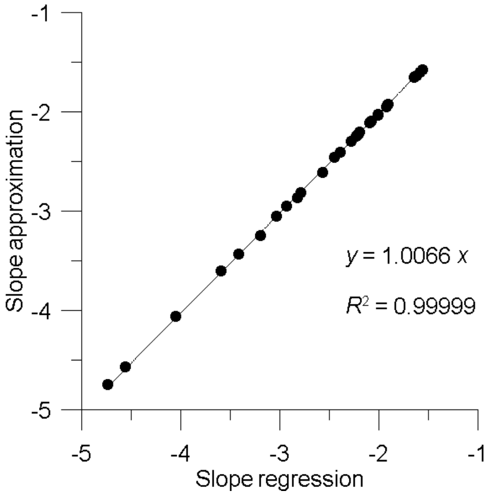

Figure 2. Relation between the slope of the log-log relation as calculated by regression and derived from the approximation (Eq. 11). The solid line is the regression through the data and the origin.

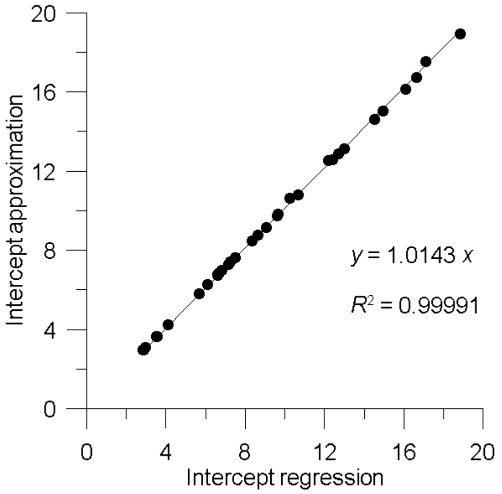

Figure 3 Relation between the intercept of the log-log relation as calculated by regression and derived from the approximation (Eq. 11). The solid line is

Table 1. The values of h_c for the Staring soils at $\varepsilon = 0.05$ either for the choice of minimum or average of $h_{c,1}$ and $h_{c,2}$, and the corresponding values of θ_c, k_c and ϕ_c.

Staring soil type$^{\$}$	***h*$_c$ (cm)**		**θ_c (cm^3 cm^{-3})**		***k*$_c$ (cm d^{-1})**		**ϕ_c (cm^2 d^{-1})**	
	min	**avg**	**min**	**avg**	**min**	**avg**	**min**	**avg**
zandB1	-226	-130	0.126	0.179	$1.16\ 10^{-02}$	$8.51\ 10^{-02}$	-1.00	-4.24
zandB2	-270	-144	0.167	0.215	$9.66\ 10^{-03}$	$4.57\ 10^{-02}$	-1.79	-4.49
zandB3	-490	-271	0.172	0.224	$5.85\ 10^{-03}$	$3.35\ 10^{-02}$	-1.47	-4.65
zandB4	-540	-284	0.203	0.252	$6.09\ 10^{-03}$	$3.70\ 10^{-02}$	-1.81	-5.80
zavelB7	-566	-302	0.218	0.252	$2.27\ 10^{-03}$	$9.66\ 10^{-03}$	-0.99	-2.24
zavelB8	-1034	-554	0.223	0.261	$1.33\ 10^{-03}$	$4.42\ 10^{-03}$	-1.47	-2.63
zavelB9	-1476	-794	0.204	0.246	$1.13\ 10^{-03}$	$3.79\ 10^{-03}$	-1.77	-3.17
kleiB10	-1858	-957	0.258	0.292	$3.97\ 10^{-04}$	$1.15\ 10^{-03}$	-1.22	-1.82
kleiB11	-764	-401	0.440	0.469	$6.22\ 10^{-04}$	$1.72\ 10^{-03}$	-0.83	-1.20
kleiB12	-647	-339	0.418	0.442	$4.28\ 10^{-04}$	$1.25\ 10^{-03}$	-0.42	-0.65
leemB13	-952	-520	0.171	0.217	$1.20\ 10^{-02}$	$4.59\ 10^{-02}$	-9.34	-19.53
leemB14	-1947	-1045	0.211	0.250	$1.09\ 10^{-04}$	$5.54\ 10^{-04}$	-0.13	-0.36
veenB16	-576	-309	0.406	0.480	$4.04\ 10^{-03}$	$1.34\ 10^{-02}$	-2.52	-4.48
veenB17	-769	-405	0.495	0.539	$1.91\ 10^{-04}$	$8.00\ 10^{-04}$	-0.12	-0.26
veenB18	-681	-348	0.513	0.565	$6.21\ 10^{-04}$	$2.41\ 10^{-03}$	-0.41	-0.82
zandO1	-166	-101	0.073	0.123	$1.20\ 10^{-02}$	$1.14\ 10^{-01}$	-0.56	-3.22
zandO2	-218	-128	0.102	0.150	$5.89\ 10^{-03}$	$5.15\ 10^{-02}$	-0.42	-2.15
zandO3	-337	-191	0.103	0.145	$4.74\ 10^{-03}$	$3.30\ 10^{-02}$	-0.66	-2.60
zandO4	-460	-254	0.129	0.169	$2.92\ 10^{-03}$	$1.78\ 10^{-02}$	-0.66	-2.21
zandO5	-68	-42	0.063	0.107	$2.09\ 10^{-02}$	$2.05\ 10^{-01}$	-0.38	-2.29
zandO6	-607	-326	0.165	0.196	$1.23\ 10^{-02}$	$4.84\ 10^{-02}$	-6.16	-13.06
zavelO8	-685	-370	0.216	0.263	$2.72\ 10^{-03}$	$1.20\ 10^{-02}$	-1.32	-3.16
zavelO9	-904	-476	0.193	0.244	$1.49\ 10^{-03}$	$6.28\ 10^{-03}$	-1.08	-2.40
zavelO10	-1118	-596	0.262	0.303	$7.00\ 10^{-04}$	$2.51\ 10^{-03}$	-0.76	-1.45
kleiO11	-705	-372	0.281	0.308	$1.04\ 10^{-03}$	$3.96\ 10^{-03}$	-0.67	-1.35
kleiO12	-1399	-716	0.373	0.411	$2.75\ 10^{-04}$	$8.22\ 10^{-04}$	-0.60	-0.92
kleiO13	-807	-423	0.447	0.471	$3.14\ 10^{-04}$	$9.10\ 10^{-04}$	-0.39	-0.59
leemO14	-1887	-1074	0.113	0.160	$9.69\ 10^{-04}$	$6.03\ 10^{-03}$	-0.81	-2.89
leemO15	-1416	-737	0.209	0.248	$2.60\ 10^{-04}$	$1.70\ 10^{-03}$	-0.20	-0.67
veenO16	-856	-464	0.387	0.480	$6.34\ 10^{-04}$	$2.47\ 10^{-03}$	-0.44	-0.94
veenO17	-851	-455	0.450	0.527	$9.61\ 10^{-04}$	$3.60\ 10^{-03}$	-0.74	-1.47

$^{\$}$: zand = sand; klei = clay; zavel = loam; leem = silt; veen = peat

Table 1 shows the critical values of h_c, either based on the minimum or the average of $h_{c,1}$ and $h_{c,2}$, and the corresponding values of water content, hydraulic conductivity and matric flux potential. The expression for the matric flux potential for the $k(h)$ relationship given by Eq. (10) reads

$$\phi = k_s m^2 |\alpha h|^{-(2+m\lambda)n} \frac{h}{1-n(2+m\lambda)} = k\frac{h}{1-n(2+m\lambda)} \qquad (18)$$

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Climate Change: In the balance

Every six or so years, the IPCC produces a three-part encyclopedia of the climate. The first, on the science of climate change, came out last September. It argued that the process is accelerating even though the world's surface temperatures are currently flatlining (a phenomenon most climate scientists regard as merely a pause in an upward trend). This second volume asks how the climate is affecting ecosystems, the economy and people's livelihoods.

From the human point the most crucial such changes will be on land, and will concern where particular crops can be grown. A warmer climate lengthens growing seasons and more carbon dioxide in the atmosphere should stimulate photosynthesis. The previous IPCC assessment, in 2007, therefore said that yields of the world's main crops—wheat, rice, maize and soyabeans—would improve in temperate and cold climates, offsetting declines elsewhere. Some argued, on this basis, that a modest amount of warming might be good for people.

The new report pours cold water on that idea. It confirms that tropical yields will decline if the temperature rises by 2°C (which is all but inevitable) but finds that the offsetting benefits in temperate zones will be smaller than once thought. Rain-fed crops (as opposed to those watered by irrigation), which are often grown in the tropics, do respond to higher levels of carbon dioxide, but the effect is counteracted by rising temperatures. Plants like long growing seasons but many (especially maize) hate temperature spikes: even one day above 35°C at the wrong time of their life cycles can damage them. And rates of photosynthesis in maize, sorghum and sugarcane (called C4 cereals, because of the details of their photosynthetic pathways) do not respond to changes in CO_2 concentrations in the way that C3 cereals, such as wheat and rice, do, so the effect of more carbon dioxide on crops is patchy.

At the moment, the report concludes, wheat yields are being pushed down by 2% a decade compared with what would have happened without climate change; maize is down by 1% a decade; rice and soyabeans are unaffected. Over time, this could worsen. Roughly half of studies of likely cereal yields over the next ten years forecast an increase, whereas the other half forecast a decline. Forecasts for the 2030s are even more sobering: twice as many predict a fall as a rise.

Farmers are always trying out new crop varieties, but increasingly those varieties will have to be drought-resistant. That may mean choosing between different aims, for there is often a trade-off between drought resistance and yield.

This way of looking at the climate is new for both scientists and policymakers. Until now, many of them have thought of the climate as a problem like no other: its severity determined by meteorological factors, such as the interaction between clouds, winds and oceans; not much influenced by "lesser" problems, like rural development; and best dealt with by trying to stop it (by reducing greenhouse-gas emissions). The new report breaks with this approach. It sees the climate as one problem among many, the severity of which is often determined by its interaction with those other problems. And the right policies frequently try to lessen the burden—to adapt to change, rather than attempting to stop it. In that respect, then, this report marks the end of climate **exceptionalism** and the beginning of **realism**.

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WISPAS is produced by Brent Clothier and Christine Lamont. If you have any material that you think may be suitable for the next issue of WISPAS please contact Brent or Christine. WISPAS is published by Plant & Food Research.

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