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Water Repellency in a New Zealand Development Sequence of Yellow-Brown Sands

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Abstract

A series of sands on the west coast of the lower North Island, New Zealand, were studied to investigate the effects of time, topography and vegetation cover upon the development of soil water repellency. Severe repellency was measured with the molarity of ethanol droplet (MED) index in the Waitarere and Motuiti dune phase sands, of age <130 years and *c.* 500 years respectively. In each dune phase, the dune sands were more repellent than the lower lying soils of the sand plains. Low or zero MED values were measured in the 1600–6000 year old Foxton dune phase sands and 10 000–25 000 year old Koputaroa dune phase sandy loams under either pasture or native bush. There was no consistent relationship between bush or pasture cover and repellency severity in the Foxton and Koputaroa soils, however, the species composition of the pasture and bush differed.

The Waitarere sand was the most repellent soil, despite a low organic carbon content. The carbon content profiles of most of the soils did not appear to be related to the respective MED profiles of repellency severity. The MED values of the surface layer from five dune sands were generally related inversely to the fulvic acid (FA) content and proportionally to the humic acid to fulvic acid ratio (HA/FA), which were measured in a previous study. The pH of the five soils ranged from 5·61 to 6·89, with no apparent relationship between pH and MED.

A study of soil water content indicated that repellency reduced rainfall infiltration into the Waitarere and Motuiti sands and the Himatangi sand, found on elevated sand plains. The most severely repellent sands had the greater variability in soil water content after rainfall.

Keywords: water repellency, development sequence, MED, carbon content, humic and fulvic acids, infiltration.

Introduction

Water-repellent soils display hydrophobic properties with a consequent reduction in infiltration (Brandt 1969) which may cause accelerated runoff and erosion (Krammes and Osborn 1969) and reduce plant establishment and growth (Osborn *et al.* 1964; Bond 1972). The effects, development and measurement of repellency have been reviewed by Wallis and Horne (1992). The Himatangi sand, a yellow-brown sand (Aquic Udipsamment) found on the west coast of the lower North Island, suffers from severe repellency when dry (Wallis *et al.* 1990*a*). The Himatangi sand forms part of a development sequence of yellow-brown sands which has been used to study organic matter accumulation and distribution (e.g. Syers *et al.* 1970; Goh *et al.* 1976). An investigation of repellency in the soils of

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the development sequence was undertaken to study the development of repellency with time. Sites were selected (Table 1) so that the influences of organic matter, topography and vegetation upon repellency development could be investigated.

Chronosequences, in which the age of a series dominates their development, have been used to study many soil processes (e.g. Jenny *et al.* 1949; Crocker and Dickson 1957; Vreeken 1975). However, true 'chronosequences' are not found in nature because it is not possible for all other state factors (Jenny 1961) to remain independent of the time variable. For example, in the yellow-brown sand development sequence, rainfall ranges from about 850 mm at the coast to about 950 mm inland, and vegetation ranges from coastal grasses and scrub to inland forest (Cowie *et al.* 1967). Therefore the term 'development sequence' has been applied to the soils studied.

The soils were classified in the 'yellow-brown sand' group by Taylor (1948) and comprise 2% of the North Island land area (Gibbs 1980). Claridge (1961) found that the sand parent material of the soils contained predominatly quartz and feldspar minerals, with small amounts of mica. Most sand grains had a diameter of 0·15–0·3 mm and the proportion of silt and clay increased from <1% in the youngest soil to 10% silt and 20% clay in the oldest soil. Claridge postulated that most of the silt and clay in the older soils was not derived from weathering *in situ* but from wind-blown deposits and volcanic ash.

Cowie (1963) recognized four distinct dune-building phases in the yellow-brown sands. Sharp differences in soil development between each phase indicated that dune formation was discontinuous. He considered that periods of vegetation destruction in response to either climatic change, volcanic eruptions or peoples influence have lead to increased sand deposition at the beaches and/or dune destabilization. Pollen analyses (McIntyre 1963), radiocarbon dating and tephra chronology were used to support this hypothesis (Cowie 1964).

Cowie (1963) reported that the Waitarere Phase is found along a coastal belt 400 m to 3 km wide which was destablized by overgrazing and burning in the 1860s and is therefore <130 years old. The dunes and sand plains of the Motuiti Phase form a belt up to 10 km wide inland of the Waitarere dunes. Radiocarbon dating and buried Maori occupation material indicated that the Motuiti dunes started to advance about 750 years ago. From the degreee of soil profile development, Cowie (1963) concluded that the Motuiti dunes became stabilized about 500 years ago. The dunes of the Foxton Phase form a belt 3–6 km wide inland of the Motuiti dunes and were dated by Cowrie (1963) at 2000 to 4000 years old. Shepherd (1987) found that the most inland Foxton dunes had become stabilized *c.* 1600 years ago, and would have been initiated at the coast *c.* 6000 years ago. Cowie (1963) only found the oldest dune phase, Koputaroa, in small areas of northern and southern Manawatu. He explained that their limited extent may be due to a formative relationship with river courses rather than with the sea. He further suggested that the dunes are 10–15 000 years old, however, subsequent dating of the interbedded Aokautere Ash (Wilson *et al.* 1988) would place the Koputaroa Phase at *c.* 22 500 years old. Koputaroa dunes are now considered to be coeval with Ohakean loess (10–25 000 years) and have been shown to be of marine origin (Shepherd 1985).

Cowie *et al.* (1967) and Cowie (1968) described the pedology of the yellow-brown sands. The soils showed increasing soil development with increasing age.

Cowie (1968) described the marked effect of topography upon soil development within a dune phase and pointed out that topography affects the soil microclimate, including soil temperature and moisture, and the vegetation. Cowie (1968) noted that the topsoil of the Foxton black sand, developed under scrub, was very dark brown or black but the Foxton brown sand, developed under forest, had a greyish or reddish brown topsoil. Bracken fern (*Pteridium acquilinum* var. *esculentum*) is known to impart very black soil coloration (Birrell 1966).

Repellency is widely acknowledged as the result of an organic coating around soil particles (Bond 1969). High magnification of repellent sand grains has shown the presence of an organic coating which was not present on sand grains from nonrepellent soil (Wilkinson and Miller 1978; Rankin and Ross 1982). Wallis *et al.* (1990*a*) reported a relationship between repellency severity and carbon content in the Himatangi sand.

The specific nature of the organic coating surrounding repellent soil particles has been the subject of much research and contention. A number of researchers have proposed that the humic acid (HA) fraction is responsible (Savage *et al.* 1969; Roberts and Carbon 1972; Adhikari and Chakrabarti 1976; Nakaya *et al.* 1977). In contrast, Miller and Wilkinson (1977) implicated fulvic acid (FA) in repellency development.

The mechanism by which HA and FA influence repellency is unknown, however, it may be due to soil adsorption of certain molecular fractions and/or the influence of soluble molecules upon the surface tension of rain or irrigation water (as described below). Evidence for an adsorption mechanism has been presented by a number of authors (e.g. Bozer *et al.* 1969; Fink 1970; Ma'sham *et al.* 1988), who have added synthetic amphiphilic chemicals to nonrepellent sand and measured increased repellency with increased chemical addition, up to a maximum repellency level. Bozer *et al.* (1969) suggested that amphiphilic molecules (e.g. fatty acids) absorb to sand grains *via* the hydrophilic end, leaving the hydrophobic end exposed to create the 'new surface' of the soil particle.

The balance between HA and FA in the soil and the soil pH may influence repellency development. Chen and Schnitzer (1978) demonstrated that both HA and FA reduced the surface tension of water significantly. The rate at which a liquid wets a solid by capillary rise is dependent upon the surface tension of the liquid, as described in equation (1):

$$h = \frac{2\gamma \cos\theta}{\rho g r}, \tag{1}$$

where h is the height of capillary rise; θ is the liquid–solid contact agent; ρ is the liquid density; g is the gravitational constant; r is the effective pore radius; and γ is the liquid surface tension.

Zisman (1964) described the 'critical surface tension' (γ_c) as the highest liquid surface tension that will wet a particular solid at a zero constant angle ($\theta = 0°$; $\cos\theta = 1$). Within the range $\gamma > \gamma_c$, the lowering of the surface tension will result in a lower contact angle, θ, and improved wetting. Chen and Schnitzer (1978) concluded that the dissolution of humic substances should therefore result in improved wettablity of water-repellent soils.

Chen and Schnitzer (1978) found that FA was soluble in water at any soil pH value, whereas HA was water-soluble only at pH >6·5. The surface tension of HA and FA solutions also decreased with increased pH. The liming of soil to increase pH would therefore increase the ability of resident FA (and HA at pH >6·5) to increase infiltration into repellent soil. Jackson and Gillingham (1985) reported that lime addition in several New Zealand field trials resulted in rapidly increased soil moisture response. This moisture response was most evident in late summer/early autumn, particularly after dry periods. They found that liming had reduced soil repellency as measured by capillary rise and water drop penetration time.

Chen and Schnitzer (1978) noted that if there is a deficiency of FA in the soil solution, repellency would be more severe. Singer and Ugolini (1976) found that the repellency of forest soil and litter was significantly correlated with the HA/FA ratio. FA is known to leach with soil development because of its solubility across the pH range (Schnitzer and Desjardins 1969). As soils develop, the HA/FA ratio would tend to increase, with a consequent increase in repellency. Goh and Reid (1975) and Goh *et al.* (1976) used the yellow-brown sand development sequence to provide evidence for the change in topsoil HA/FA ratio over time. They found that HA was concentrated principally in the surface horizons, especially in the younger soil profiles, and rarely extended below 500 mm. FA extended to 1 m depth, and the amount in the lower horizons increased with increasing soil age.

The purpose of this study was to:

(i) measure the severity of repellency in a range of soils of contrasting age, topographic position and vegetation cover;
(ii) identify the relationship between repellency and carbon content in the soils;
(iii) determine the relationship between repellency and the topsoil HA/FA ratio, the FA content and the pH of the soils;
(iv) evaluate the effect of repellency upon the water content of the soils under natural rainfall.

Methods

The soils and site positions used in this study (Table 1) were selected in positions as close as possible to the sites used in the study of soil organic matter by Goh *et al.* (1976) (Cowie; pers. comm. 1991).

The sites were sampled in late November 1990. Four pits were excavated at each site and bagged soil samples (about 300 g) were removed from 0–50, 50–100, 100–150 and 150–200 mm depth. Corers 50×50 mm were used for bulk density measurement from 50 and 150 mm depth, from two pits at each site. Soil samples were air-dried and repellency was measured with the Molarity of Ethanol Droplet (MED) test, first proposed by Watson and Letey (1970) and developed by King (1981). The MED test measures the molarity of an aqueous ethanol droplet required for soil infiltration within 10 s. Ethanol lowers the liquid surface tension and solid–liquid contact angle, increasing the rate of infiltration into water-repellent soil. King (1981) provided the following guidelines for interpretation of MED values: MED = 0, nonrepellent; MED < 1, low repellency; MED 1·0–2·2, moderate repellency; MED > 2·2, severe repellency. Subsamples of approximately 10 g were placed in Petri dishes and lightly pressed flat. MED was tested using an eye-dropper, stopwatch and ethanol solutions ranging from 0 to 5 molar in 0·2 molar increments. A zero MED value may not imply zero repellency because the MED test is not sensitive for soils with low degrees of repellency (King 1981; Wallis *et al.* 1991). Wallis *et al.* (1991) found that soils which measured MED = 0 had repellency which significantly decreased the rate of water infiltration. However, the MED test proved useful to determine the large differences in repellency of the soils in this study.

Table 1. Site descriptions for a development sequence of yellow-brown sands

Dune phase	Soil type	Topographich position	Current dominant plants	Grid reference (NZMS260;S24,25)
—	Beach sand	Mean high water	(Bare of vegetation)	961714
Waitarere	Waitarere sand	Dune	blue lupin,[A] brackin[B]	963714
	Hokio sand, peaty phase	Low lying sand plain	raupo[C] red rush[B]	963713
Motuiti	Motuiti sand	Dune	bracken,[B], browntop,[E] subterraneum clover[F]	974722
	Himatangi sand	High sand plain	browntop,[E] sub. clover[F]	974723
	Pupepuke black sand	Low-lying sand plain	browntop,[E] sub. clover[F]	975722
Foxton	Foxton black sand[1]	Dune	browntop,[E] sub. clover[F]	009689
	Foxton brown sand[2]	Dune	tawa[G]	032686
Koputaroa	Koputaroa sandy loam	Dune	ryegrass,[H] white clover[1]	039669
	Koputaroa sandy loam	Dune	tawa[G]	041668

[1] Formed under scrub vegetation.
[2] Formed under forest vegetation.
[A] *Lupinus augustifolius.*
[B] *Pteridium aquilinum var. esculentum.*
[C] *Typha muelleri.*
[D] *Leptocarpus simplex.*
[E] *Agrostis tenuis.*
[F] *Trifolium subterraneum.*
[G] *Beilschmiedia tawa.*
[H] *Lolium perenne.*
[I] *Trifolium repens.*

Subsamples (about 0·5 g) were placed in a Leco induction furnace to determine the carbon content at each depth (Nelson and Sommers 1982). The carbon content of beach sand was not determined. Subsamples of 10 g were used to measure soil pH in water (1 : 2·5 w/w) at each depth.

A Time Domain Reflectometer (TDR) (Topp and Davis 1985) was used to measure four replicates of the volumetric water content, θ, from 0–200 mm depth at each site when the soil samples were taken in November. The TDR was also used to measure θ (0–200 mm depth) at each site before and after a period of rainfall in January 1991.

Discussion of Results

Water Repellency

The extent of soil development had a marked effect upon the repellency (MED) profiles of the nine sites (Fig. 1). The beach sand measured MED = 0 at all depths, however, severe repellency to 200 mm depth had developed in <130 years in the Waitarere sand. Unexpectedly, repellency declined with increasing soil age from the Waitarere sand until MED = 0 was measured from 0–200 mm depth for the Koputaroa sandy loam under pasture.

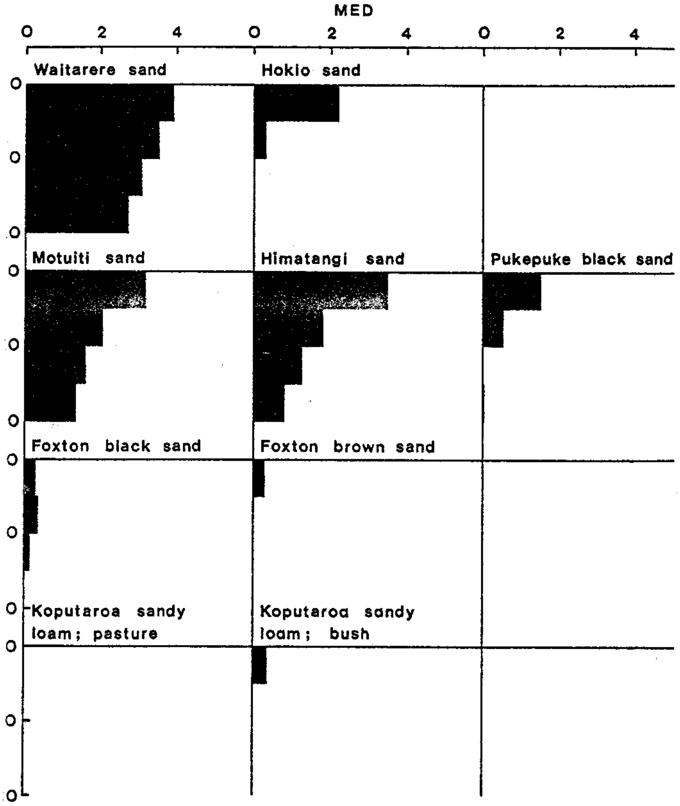

Fig. 1. Soil water repellency (MED) profiles of nine yellow-brown sands comprising a soil development sequence. Standard deviations for the 0–50 mm soil layers are as follows: Waiterere, 0·72; Hokio, 0·82; Motuiti, 0·59; Himatangi, 0·99; Pukepuke, 0·35; Foxton black, 0·20; Foxton brown, 0·26; Koputaroa (bush), 0·57.

The Waitarere and Motuiti dune phase soils provided an opportunity to assess the effect of topography upon repellency development. In both dune phases, repellency was most pronounced in the dune soils and least in the low-lying, imperfectly or poorly drained soils. Topography may affect repellency development by influencing the past and/or present vegetation. Many studies have identified a relationship between plant species and repellency (e.g. Adams *et al.* 1969; Richardson and Hole 1978; McGhie and Posner 1981) and the microorganisms associated with the plants may also be involved (Bond 1964; McGhie and Posner 1981).

Topography may also affect repellency, because repellency is expressed most strongly as a soil dries (Wallis *et al.* 1990*a*). Although the peaty phase of the Hokio sand measured MED 2·2 in an air-dry state, the soil is low-lying and has been found to remain consistently wet throughout summer (Table 3). Therefore the Hokio soil would not be expected to resist water infiltration to a marked extent. The watertable in the Hokio soil was found at approx. 400 mm throughout the 1990/91 summer and is expected to rise to the soil surface periodically in winter. The other low-lying soil, the Pupepuke black sand, was found to be dry over summer 1990/91, however, the profile exhibited mottling at <300 mm dpeth which indicated a fluctuating watertable.

The effect of bush *v.* pasture cover upon repellency severity was inconsistent between the soils of the Foxton and Koputaroa dune phases. The Foxton black sand, developed under scrub and currently under pasture, was found to have a greater depth of repellent soil than the Foxton brown sand which was developed and is currently under native bush. In contrast, the Koputaroa sandy loam under pasture measured MED = 0 compared with the same soil under native bush which has slight repellency at 0–50 mm depth. The effect of pasture *v.* bush was not directly comparable between the two dune phases because the species composition of the pasture and bush was different (Table 1).

Organic Matter

A simple visual comparison between the soil carbon analysis (Fig. 2) and MED values (Fig. 1) shows that repellency was not related to the quantity of soil organic matter. Indeed, the Waitarere sand, which was the most severely repellent, had the lowest organic matter content measured. Bond and Harris (1964) found that a surprisingly small amount of organic matter (<0·1%) was necessary to produce severe repellency in Australian sands. DeBano *et al.* (1970) reported water repellency in sands with 0·02% organic matter. DeBano (1969) pointed out that the total organic matter content bore no relation to the repellency in Australian sands since some sands with >5% C were more easily wetted than others with 0·1% C. The current results and those of DeBano suggest that only a fraction of the total organic matter is responsible for repellency.

However, the profile of repellency severity within a particular soil has been related to the quantity of organic matter present. Scholl (1975) and Singer and Ugolini (1976) reported a decrease in repellency with depth which was closely associated with decreasing organic matter. Wallis *et al.* (1990*a*) reported a strong correlation ($R^2 = 0 \cdot 79$) between %C and the MED index with depth in the Himatangi sand. In this study, the MED and %C profiles also follow a similar

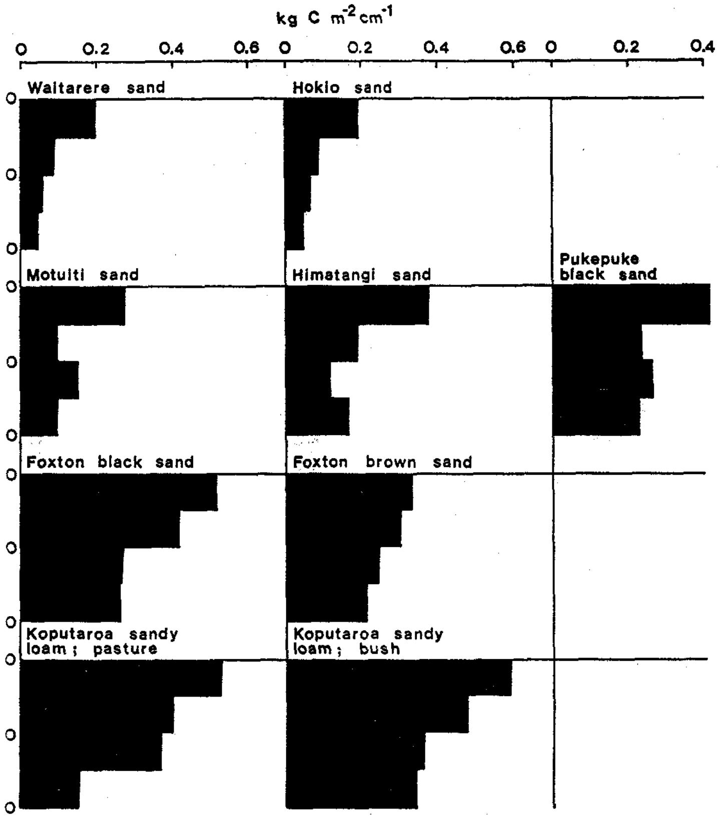

Fig. 2. Soil carbon content (C) profiles of nine yellow-brown sands comprising a soil development sequence.

Table 2. Soil water repellency (MED), humic acid (HA) and fulvic acid (FA) contents, HA to FA ratio and pH of five yellow-brown dune sands

MED and pH data for 0–50 mm soil depth; HA and FA data for the uppermost genetic soil horizon samples after Goh *et al.* (1976)

Soil	MED	HA^{A}	FA^{A}	HA/FA	pH
Waitarere sand	3·85	0·2	0·3	0·7	6·19
Motuiti sand	3·2	1·0	0·9	1·1	6·55
Foxton black sand	0·3	0·8	0·9	0·9	6·22
Koputaroa sandy loam (pasture)	0	0·4	1·8	0·2	6·89
Koputaroa sandy loam (bush)	0·4	0·5	2·4	0·2	5·61

^{A} Units are (g$\times$10^{2}, m^{-2}, cm^{-1}).

pattern in the Himatangi sand, however, in the other soils, MED and %C were apparently unrelated. This would further suggest that it is the nature rather than the quantity of the organic matter *per se.* which is the most important determinant of repellency.

The HA/FA ratio and FA content of the uppermost soil horizon of five dune soils (Goh *et al.* 1976) was compared with the average MED value for the 0–50 mm depth of each soil (Table 2). The hypotheses detailed in the Introduction would predict an inverse relationship between FA content and MED and a proportional relationship between HA/FA and MED. Although the data set is limited and there are problems matching soil depths between this study and that of Goh *et al.* (1976), the values reported in Table 2 would appear to support the hypotheses. As for the relationship between carbon content and MED (Figs 1 and 2), the interaction between soil fulvic acid and MED was not always consistent—as illustrated by the Foxton black sand and Motuiti sand (Table 2). 'Fulvic acid' is only a crude classification of organic matter and there may well be one or more components of FA which have the most profound influences on MED.

Soil pH may be an additional factor in the relationships between the HA/FA ratio and MED and the FA content and MED, as explained in the Introduction. Soil of high pH, particularly $\text{pH}>6\cdot5$ at which HA is soluble, would be expected to be less repellent. The pH values of the five soils covered a narrow range, which limited inferences that could be made regarding the influence of soil pH upon repellency. There appeared to be no relationship between pH and MED.

Soil Water Content Analysis

Large differences in soil water content were measured in November 1990 when the soil samples were taken (Table 3). In the Waitarere and Motuiti dune phases, the dune soils had consistently lower soil moisture than the low lying sand-plain soils. The severe repellency and steep relief of the dune soils would be expected to decrease infiltration and consequently the soil water content. The topographic position of the soils in relation to the watertable would also increase the water content of the low-lying soils relative to the dune soils. Scotter (1989) conducted an analysis based upon soil water statics and dynamics of the Pukepuke soil which suggested that surface soil moisture would only be influenced when the watertable is <1 m deep. During summer, the watertable of the Pukepuke soil was >1 m deep, however, in the Hokio soil, the watertable was about 400 mm from the soil surface and would be expected to influence the surface soil water content.

The effect of bush cover upon soil moisture was variable between the Foxton and Koputaroa soils in November, however, at later dates, the soils under bush

Table 3. Water content measurements of nine yellow-brown sands

Soil	Volumetric water content (θ), 0–200 mm depth			Increase 14–18/1/91)	
	Nov. 1990	14/1/91	18/1/91	θ	(mm)
Waitarere sand	7·2±5·2[A]	3·1±0·7[B]	2·2±1·5[B]	−0·9	−1·8
Hokio sand, peaty phase	62·7±0·7	55·4±4·1	56·2±6·3	0·8	1·6
Motuiti sand	17·6±4·9	5·5±0·2	7·1±1·9	1·6	3·2
Himatangi sand	19·6±5·6	5·4±0·3	8·8±3·4	3·4	6·8
Pukepuke black sand	25·8±5·3	5·6±0·2	15·0±3·9	9·4	18·8
Foxton black sand (pasture)	18·1±4·5	7·0±1·2	16·1±3·3	9·1	18·2
Foxton brown sand (bush)	29·7±1·7	13·5±2·0	20·8±3·5	7·3	14·6
Kopuraroa s.l. (pasture)	36·2±0·2	22·4±2·4	31·9±1·7	9·5	19·0
Koputaroa s.l. (bush)	35·6±1·9	26·4±2·6	34·0±3·1	7·6	15·2

[A,B] Mean and standard deviation of 4 and 10 replicates respectively.

were always more moist than the same soils under pasture. The bush canopy may have produced a more humid microclimate and reduced evaporation from the soil surface. The pasture may have also had a higher transpiration rate than the plants which comprised the bush canopy.

By January 1991, the water content of all the soils had declined. In general, the water contents were greatest in the oldest soils inland from the coast, presumably because the coastal summer rainfall was lower than the inland rainfall (Cowie *et al.* 1967). Despite the rainfall gradient, the soil moisture response to a period of rainfall during 14–17 January 1991 was most informative. The property owners at the Foxton brown sand and Foxton black sand sites measured 40 and 30 mm rainfall over the three days respectively. Unfortunately, a rainfall measurement could not be obtained near the Motuiti and Waitarere sites. Soil water contents were measured immediately after rainfall, so that evaporation was negligible.

In general, the most severely repellent soils displayed the least increases in soil water content. The water content of the Hokio soil increased slightly, while that of the Waitarere soil actually decreased, indicating that little rain fell near the coast and that rainfall upon the dry, severely repellent Waitarere sand ran off the soil surface and infiltrated into lower-lying, moist and therefore nonrepellent Hokio sand.

The effects of surface water redistribution were more marked in the Motuiti dune phase soils. All three soils had a very similar water content before rainfall, however, the water content increase in the lowest-lying, least repellent Pukepuke soil was about 9 times greater than that for the severely repellent Motuiti dune sand. Although the Himatangi sand measured a slightly higher surface-soil MED than the Motuiti sand, its moisture content increased by approximately double that of the dune soil. The Himatangi site was flat compared with the steep Motuiti dune site, which would have facilitated greater water infiltration.

The water content increases in the least repellent Foxton and Koputaroa soils were similar to that of the Pukepuke black sand. However, despite 30–40 mm measured rainfall, the water contents of the Foxton and Koputaroa soils increased by <19 mm. The rainfall may have contributed to increased soil moisture at depth >200 mm and the balance may be accounted for by a small amount of evaporation. Bush cover over the Foxton and Koputaroa soils also appears to have intercepted some rainfall, since the moisture content increase of the forest-covered soils was about 4 mm less than that for the pasture-covered soils. Spatial variability in rainfall is unlikely to account for the difference between the Koputaroa soils, because the bush and pasture sites were less than 100 m apart. However, rainfall variability may have been significant between the Foxton sites, which were 2·3 km apart.

The most severely repellent soils had the greatest variation in water content after rainfall (Fig. 3). The Hokio soil had a high water content and would not express repellency, therefore the coefficient of variation (C.V.) was low. Before rainfall, the soil water content at each site was reasonably uniform (C.V. <21%), however, after rainfall the C.V. of all soils other than the Koputaroa sandy loam under pasture increased. High spatial variability of the moisture content in repellent soils has been reported by numerous authors (e.g. Bond 1964; Hendrickx *et al.* 1988) and may be due to the pattern of present and/or past vegetation and associated soil microorganisms.

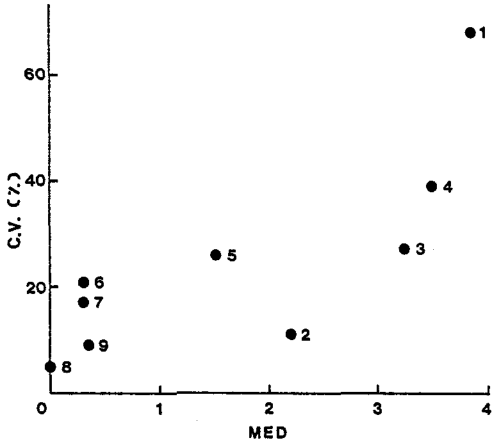

Fig. 3. Post-rainfall coefficient of variation (C.V.) of volumetric soil water content, θ (0–200 mm depth) *v.* soil water repellency, MED (0–50 mm depth) of nine yellow-brown sands comprising a soil development sequence. 1, Waitarere sand; 2, Hokio sand, peaty base; 3, Motuiti sand; 4, Himatangi sand; 5, Pukepuke black sand; 6, Foxton black sand; 7, Foxton brown sand; 8, Koputaroa sandy loam (pasture); 9, Koputaroa sandy loam (bush).

Conclusions

Severe repellency developed in less than 130 years in a yellow-brown sand with limited organic carbon. Repellency severity declined in soils of increasing age, suggesting that the nature rather than the quanity of organic matter in soil is the most important determinant of repellency development.

The dune soils were more repellent than the sand plain soils of equal age. Soil topographic position affects plant and soil microorganism populations which comprise the origin of the hydrophobic organic material responsible for repellency. Also, topography affects soil moisture, which in turn affects the expression of repellency.

Repellency development did not appear to be related to the current vegetation cover of either bush or pasture in the Foxton and Koputaroa dune phases, however, it is important to note that the composition of the bush and pasture in the two dune phases differed. Repellency may be related to particular past or present species of plants and associated microorganisms, which would help to explain the spatial variability of water content measured in the repellent soils.

Repellency severity of five dune sands appeared to be related to the HA/FA ratio and the FA content as proposed by a number of authors. Soil pH, which affects HA and FA solubility, did not appear to be related to repellency, although the pH range of the soils was limited. The HA and FA are arbitrary organic fractions based upon extraction conditions and comprise many compounds. Identification of the specific compound(s) responsible for repellency would be more useful, and is the subject of ongoing research.

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