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Subject: Eng – Geophysical Investigations **Date:** 26 October 2010

To: Steve Chick
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Purpose:
Two dam structures in the Blackwood Watershed of southwest Nebraska have been breached as a result zones of weakness developing from desiccation and differential settlement of earthen materials. There are fourteen similar structures in the Blackwood Watershed that have the potential to experience similar catastrophic events. The potential of using electromagnetic induction (EMI) to detect fissures and zones of weakness in similar earthen structures was evaluated. Structures 32-A and P-2 were surveyed with EMI methods. Training on the calibration and operation of the EM31 and EM34-3 meters were provided to geologists participating in this study.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Ted Huscher, Geologist, USDA-NRCS, Lincoln, NE
Tom Cyre, Geologist, USDA-NRCS, Salina, KS
James Kearney, Geologist, USDA-NRCS, Lincoln, NE

Activities:
All activities were completed during the period of on 6 and 7 October 2010.

Summary:

1. Electromagnetic induction permits the visualization of trends and localized anomalous conditions that can be missed by all but the most close-spaced drilling programs. Using two different meters, the potential of EMI to detect zones of weakness in earthen dams was evaluated on two structures in southwestern Nebraska. The results and observations obtained from these surveys can help geologists determine the most appropriate meter and approach to non-invasive surveys of other potentially at risk structures.

2. At Blackwood 32-A, an EMI survey was conducted with an EM31 meter. While this survey lacked sufficient resolution to identify individual fissures, it did reveal a presumably higher clay content zone or layer in the west alluvial foundation area. However, a narrow, sediment-filled fissure (see Fig. 1) observed in a cut-wall was too small and lacked sufficient contrast to be detected with this meter.

3. At structure P-2, EMI surveys were conducted with both the EM31 and EM34 meters. Results suggest that the EM31 meter can detect zones of weakness in earthen structures, while the deeper-

sensing EM34-3 meter can disclose major differences in underlying fill materials, stratigraphy and lithology.

4. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil borings). The use of geophysical methods can reduce the number of cores, direct their placement, and supplement their interpretations.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to be of assistance in this study.

JONATHAN W. HEMPEL
Director
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Technical Report on Geophysical investigations of two dam sites in the Blackwood Watershed in southwest Nebraska on 6 and 7 October 2010.

Jim Doolittle

Background:

Two earthen dams in the Blackwood Watershed of southwest Nebraska have been breached because of the development of fissures and zones of weakness. These features are produced by differential settlement and desiccation of the earthen materials that compose these structures. The purpose of this investigation was to assess the potential of using non-invasive electromagnetic induction (EMI) methods to detect fissures and zones of potential weakness in earthen structures.

Figure 1. Ted Huscher points to a fissure observed at Structure 32-A.

In the investigation of earthen structures, geophysical methods can permit the visualization of trends and localized anomalous conditions, which are often overlooked by all but the most closely-spaced drilling programs (Butler and Llopis, 1990). Geophysical methods, such as direct current (DC) resistivity, transient electromagnetic (TEM) and self-potential (SP), have been used to map seepage paths, monitor temporal and spatial changes in seepage, and direct remedial measures on earthen dams (Buselli and Lu, 2001). The response of these methods is strongly dependent on changes in moisture contents. The use of electromagnetic induction (EMI) for the investigation of earthen structures has not been as widely reported as these other geophysical methods.

Electromagnetic induction is a noninvasive geophysical tool. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features.

Electromagnetic induction can provide, in a relatively short time, a large number of spatially-referenced measurements. Maps prepared from properly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and locating drilling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity (EC_a) of earthen materials. Apparent conductivity is the weighted, average conductivity measurement for a column of earthen materials (Greenhouse and Slaine, 1983). In earthen materials, EC_a is directly associated with soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976). Apparent conductivity is typically expressed in milliSiemens/meter (mS/m).

Electromagnetic induction measures vertical and lateral variations in EC_a. Values of EC_a are seldom diagnostic in themselves. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations are normally used.

The depth of observation and measured response of an EMI meter are influenced by coil orientation, coil separation, and frequency, as well as the conductivity of the profiled material(s). The EMI response is not uniform with depth; surface and shallow layers contribute more to the overall response than deeper layers. The orientation of the transmitter and receiver coil axes (with respect to the ground surface) affects the response from materials at different depths (McNeill, 1980). For example, in the shallower-sensing horizontal dipole orientation, meters are more sensitive to near surface materials. In the deeper-sensing vertical dipole orientation, meters are more sensitive to deeper materials. The greater the intercoil spacing (spacing between transmitter and receiver coils), the greater the depth of penetration, the larger the volume of earthen materials profiled, and the lower the resolution of subsurface features. Slavich (1990) reported that the actual depth of observation would vary depending on the apparent conductivity (EC_a) of the profiled material(s). The depth of penetration decreases with increasing conductivity. Greenhouse et al. (1998) noted that EMI instruments do not penetrate a fixed distance under all circumstances.

Butler and Llopis (1990) have categorized EMI as a primary geophysical tool for the detection of anomalous seepage zones in earthen dams. The resolution of subsurface features with EMI, however, is inferior to that obtained with electrically resistivity and ground-penetrating radar. In addition, as with all geophysical methods, the resolution of subsurface features decreases with increasing observation depths. The detection of fissures and zones of weakness in earthen structures with EMI depends on the size, depth and composition of these features.

Equipment:
The EM31, and EM34-3 meters (Geonics Limited; Mississauga, Ontario) were used in the investigations [1]. These meters require no ground contact. The EM34-3 meter requires two people (Fig. 2) and the EM31 meter requires only one person (Fig. 3) to operate. The EM31 meter weighs about 12.4 kg (27.3 lbs), has a 3.66 m intercoil spacing, and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter has effective penetration depths of about 3.0 and 6.0 meters in the horizontal dipole (HDO) and vertical dipole (VDO) orientations, respectively (McNeill, 1980). McNeill (1980) describes the principles of operation for the EM31 meter.

McNeil (1980) and Geonics Limited (1990) describe the operation of the EM34-3 meter. The EM34-3 meter consists of receiver and transmitter coils, three reference cables (10, 20, and 40 m), and receiver and transmitter consoles. The frequency used by the EM34-3 meter is dependent on the intercoil spacing: 6400 Hz for the 10 m, 1600 Hz for the 20 m, and 400 MHz for the 40 m intercoil spacings. In this investigation, a 20-m intercoil spacing with coils held vertically on the ground surface in the HDO was

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

used (Fig. 1). The HDO was used rather than the deeper-sensing VDO because the HDO configuration is relatively insensitive to misalignment of the two coils (McNeil, 1980). In the HDO configuration, with a 20 meter intercoil spacing, the nominal penetration depth of the EM34-3 meter is approximately 15 m.

Figure 2. Ted Huscher and Tom Cyre conducts an EMI survey using an EM34-3 meter with a 20-m intercoil spacing) at Structure P2.

Figure 3. Ted Huscher conducts an EMI survey with the EM31 meter at Structure P2.

A Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced EMI data collected with the EMI meters.[2] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used with the meters to record and store both GPS and EMI data[2]. The newly developed RTM31 (Geomar Software, Inc., Mississauga, Ontario) and the Dat34W programs (Geonics Limited, Mississauga, Ontario) were used with the EM31 and EM34-3 meters, respectively, to display and record both GPS and EC_a data on the Allegro CX field computer.[2] The RTmap31 system provides immediate tracking and viewing capabilities of the collected EMI data. With these capabilities, operators can visually correlate spatial EC_a patterns with visible surface features as the survey progresses. In addition, surveys are carried out faster, sites can be more uniformly covered (avoiding skipping areas), and unnecessary overlap of survey lines prevented.

To help summarize the results of the EMI surveys, the SURFER for Windows (version 9.0) software (Golden Software, Inc., Golden, CO) was used to construct the two-dimensional simulations shown in this report.[2] Grids were created using kriging methods with an octant search.

Study Sites:

<u>Structure 32-A</u>

The site (40.3497 N. Latitude, 100.9067 W Longitude) is located off of County Road 372 along the Hayes and Hitchcock County line. It is about 8.7 miles north-northwest of Culbertson, Nebraska. The structure is presently being rebuilt and the survey was restricted to relatively level, open, reworked areas. The structure is located in an area of Sulco-Ulysses silt loams on 9 to 30 % slopes, eroded (soil map unit 1833). These deep, well drained soils formed in calcareous silty loess on uplands. The Sulco soil has low clay content (8 to 17 %) and high silt (30 to 55 %) and very fine sand (30 to 60 %) contents. The Ulysses soil has slightly higher clay contents. These soils are classified as a coarse-silty, mixed, superactive, calcareous, mesic Aridic Ustorthents (Sulco); and a fine-silty, mixed, superactive, mesic Aridic Haplustolls (Ulysses).

<u>Structure P-2</u>

The site (40.2539 N. Latitude, 100.7543 W Longitude) is located in Red Willow County about 7.4 miles northwest of McCook, Nebraska. The structure is located in an area of Sulco-Ulysses silt loams on 9 to 30 % slopes, eroded (soil map unit 1833). This structure has steep faces, which were mowed prior to our arrival. The ground surface, however, is pockmarked with numerous animal burrows. The steep slope and uneven surfaces of this structure made survey work arduous and a little precarious.

Survey procedures:

The EM34-3 meter was used only at structure P-2. The meter was operated in a station-to-station mode with measurements manually triggered at stations spaced about 20-m apart. At each station, to record a measurement, the coils of the EM34-3 meter were first placed on the ground surface, then orientated in the direction of traverse and adjusted to the correct intercoil distance. With a 20-m intercoil spacing the volume of earthen materials covered by this meter is comparatively large (Fig. 2) and, as a consequence, responses are averaged across a larger area and resolution of subsurface features is relatively coarse.

The EM31 meter was used at both sites. The EM31 meter was operated VDO, and in the continuous mode (measurements recorded at 1-sec intervals). The meter was held at hip height and orientated with its long axis parallel to the direction of traverse (Fig. 3). Surveys were completed by walking in a back and forth pattern across each structure.

Results:

<u>Structure 32-A</u>

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[2] Manufacturer's names are provided for specific information; use does not constitute endorsement.

At Structure 32-A, the earthen materials surveyed with the EM31 meter had an average EC_a of about 49.7 mS/m with a range of about 27 to 165 mS/m. However, one-half of the measurements (total of 1054 measurements) collected at this structure were between about 46 and 54 mS/m.

Figure 4 is a plot of the EC_a data recorded with the EM31 meter at Structure 32-A. In this plot, the grey-colored area represents an excavated trench (center portion of plot) that is bounded on the east and west by steeply-sloping mounds of excavated materials. Differences in EC_a are believed to represent differences in clay and (to a lesser degree) moisture contents. Areas with higher clay contents (colored red and yellow in Fig. 4) appear as east-west trending strips, which represent materials that were laid down in construction of this dam (especially noticeable along the south alluvial foundation area). Areas with lower EC_a values (colored blue and green in Fig. 4) are presumed to have either lower clay contents or represent segments where the boom of the EM31 meter was too close or extended over the excavated trench in the central portion of the survey area. During the survey, a visible, sediment-filled crack (Fig. 1) was passed over with the EM31 meter. This feature, however, was too small and lacked sufficient size and contrast to be detected with the EM31 meter.

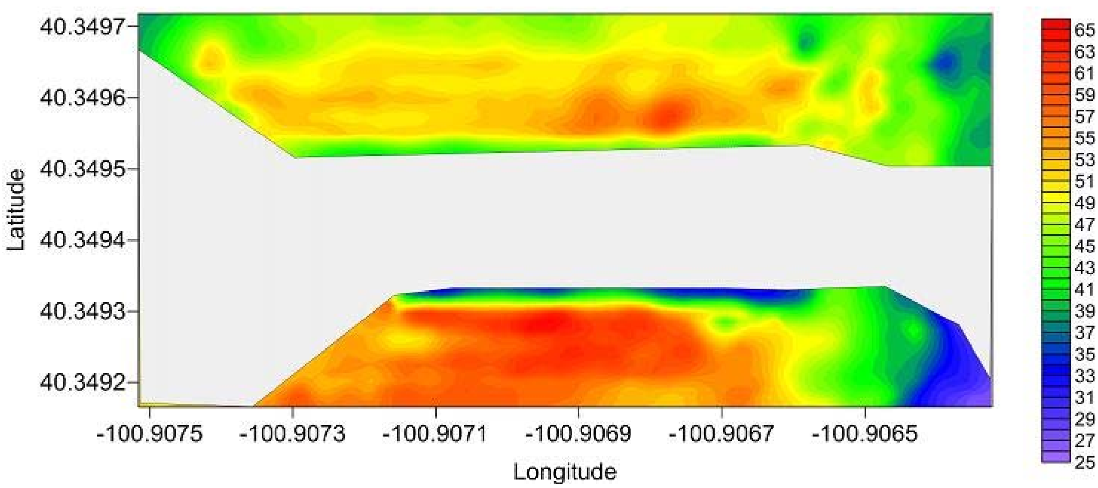

Figure 4. In this two-dimensional plot of the EC_a data collected at Structure 32-A with an EM31 meter operated in the VDO, the effective depth of penetration is about 5 m. Gray areas represent an excavated, deep trench (center) or steeply-sloping earth embankments (to the right and left of trench).

Structure P-2

Compared with Structure 32-A, the earthen material at Structure P-2 had lower, but slightly more variable EC_a. At Structure P-2, the earthen materials surveyed with the EM31 meter had an average EC_a of about 37.6 mS/m with a range of about 17 to 110 mS/m. However, one-half of the measurements (total of 9011 measurements) collected at Structure P-2 were between about 31 and 44 mS/m. With the deeper-sensing EM34-3 meter, EC_a averaged 32.1 mS/m with a range of about 19 to 44 mS/m. One-half of the EM34-3 measurements (total of only 103 measurements) were between about 29 and 36 mS/m.

Figure 5 is a plot of the EC_a data recorded with the EM31 meter at Structure P-2. In this plot, areas of higher clay and moisture contents have higher EC_a and appear in shades of yellow and red. Areas with presumably lower clay and moisture contents are in shades of green and blue. These areas represent the undisturbed soil materials along the abutments and crest of the structure. Jim Kearney commented that the natural landscape surface (shallow foundation along the abutments) is manifested by areas of lower conductivity in this plot. During the survey, Jim Kearney also noted and flagged several crevices, which occurred along the south-facing embankment slope near the east side on the dam. This zone of crevices corresponds to a region of low EC_a that is identified in Figure 5 with an arrow. Although the EM31 meter cannot identify individual fissures in earthen dams, it appears capable of detecting areas with multiple crevasses and therefore general zones of weakness and concern.

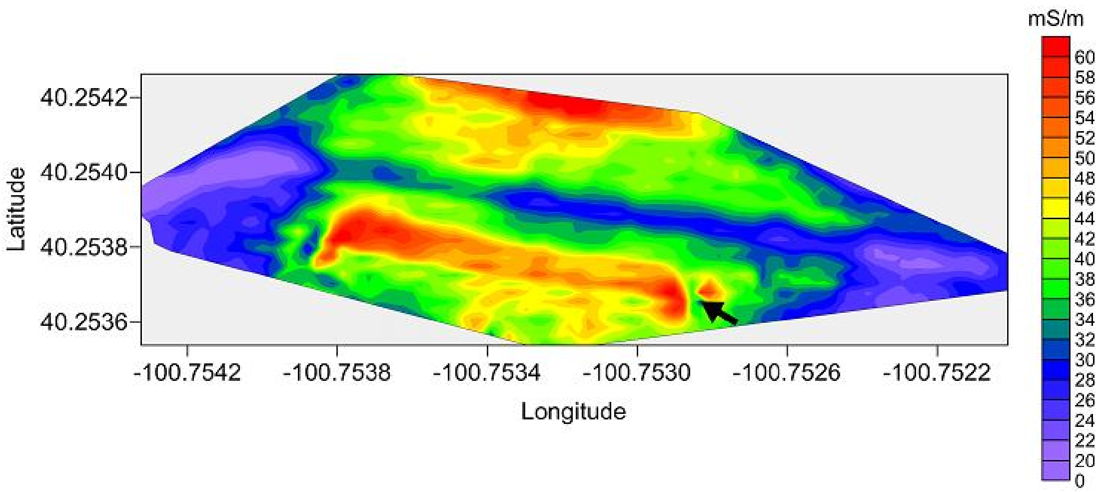

Figure 5. In this two-dimensional plot of the EC_a data collected at Structure P2 with the EM31 meter operated in the VDO, the effective depth of penetration is about 5 m. The arrow indicates a zone containing numerous observable crevasses.

Figure 6 contains two three-dimension wireframes of Structure P-2 with the EC_a data that was collected with the EM31 meter draped over the maps. The wireframe maps are 3D representations of elevation data collected during surveying with the Trimble AG114 GPS receiver. In the wireframe maps shown in Figure 6, the perspectives are from the southwest (for South Face) and the northeast (for North Face) corners of the survey area. The 3D surface maps emphasize relational spatial patterns at the dam site and provides displays that facilitate the comparison of EC_a data with surface features.

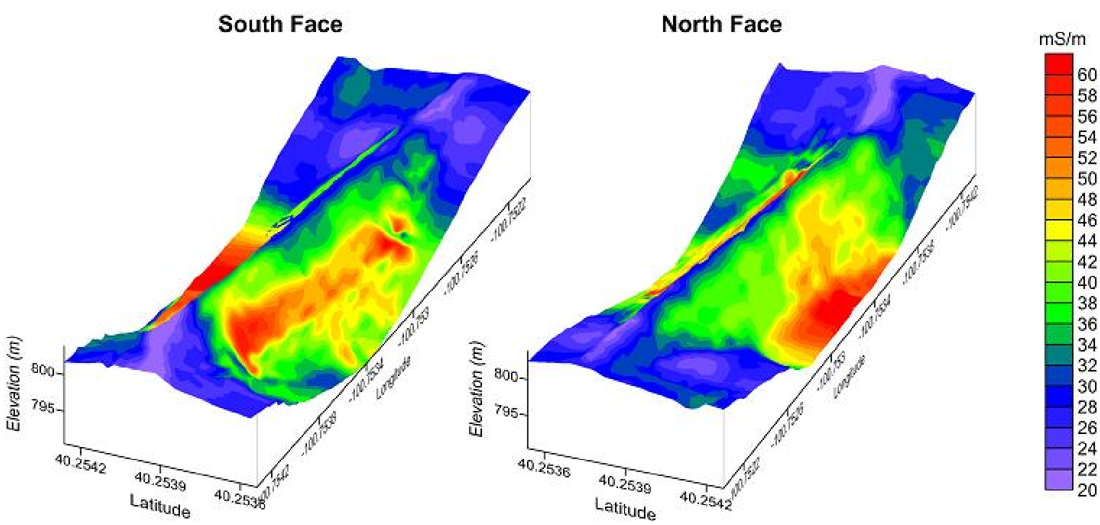

Figure 6. In these three-dimensional simulations of the EC_a data collected at Structure P2 with the EM31 meter operated in the VDO, the viewpoints are facing east for the "South Face" and west for the "North Face".

Figure 7 is a plot of the EC_a data collected with the EM34-3 meter at Structure P-2. Compared with the results obtained with the EM31 meter (Fig. 5), because of the greater depth of penetration (15-m versus 5-m) and wider intercoil-spacing (20 m versus 3.7-m) of the EM34-3 meter, EC_a has been averaged across larger volumes of earthen materials and the resolution of subsurface features is lower. However, general trends and spatial EC_a patterns are similar in both data sets. The most noticeable differences are along the crest and lower north face of the structure. Results from the EM34-3 survey shows major subsurface patterns that are related to fill materials, stratigraphy and lithology. However, the EM34-3 meter did not resolve the zone of observable crevasses in this structure.

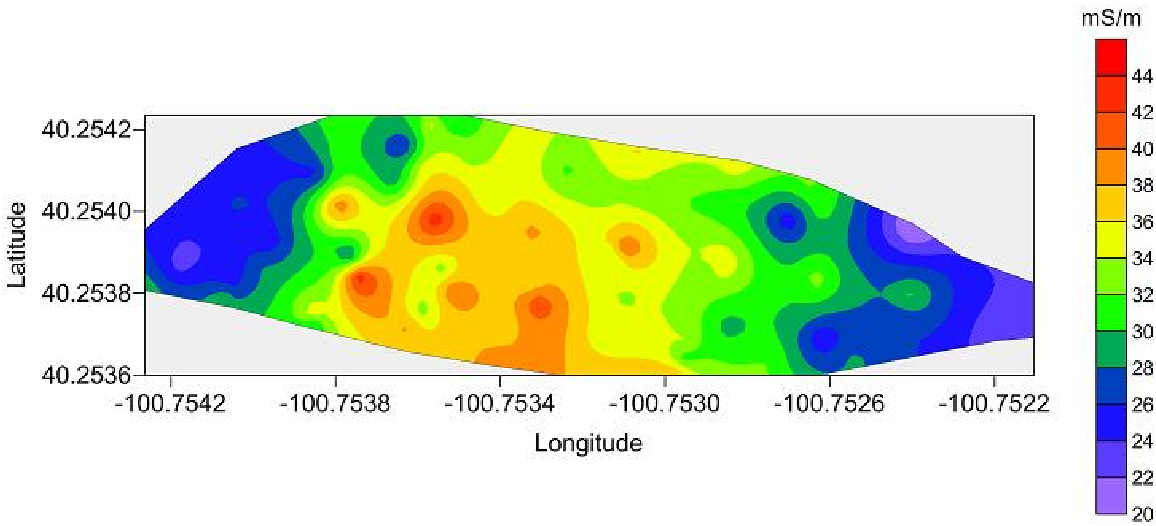

Figure 7. In this two-dimensional plot of the EC_a data collected at Structure P2 with the EM34-3 meter operated in the HDO, the effective depth of penetration is about 15 m.

References:

Buselli, G., and K. Lu. 2001. Groundwater contamination monitoring with multichannel electrical and electromagnetic methods. Journal of Applied Geophysics 48: 11-23.

Butler, D.K., and J.L. Llopis. 1990. Assessment of anomalous seepage conditions. 153-172 pp. IN: Ward, S. H. (Ed.) Geotechnical and Environmental Geophysics. Vol. II. Society of Exploration Geophysicists. Tulsa, OK.

Geonics Limited. 1990. EM34-3 & EM34-3XL Operating Instructions. Geonics Limited, Mississauga, Ontario.

Greenhouse, J. P., and D. D. Slaine. 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2): 47-59.

Greenhouse, J. P., D. D. Slaine, and P. Gudjurgis. 1998. Application of geophysics in environmental investigations. Matrix Multimedia, Canada. CD-ROM.

Kachanoski, R.G., E.G. Gregorich, and I.J. Van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

McNeill, J. D., 1980. Electromagnetic terrain conductivity measurements at low induction numbers. Technical Note TN-6. Geonics Ltd., Mississauga, Ontario.

Rhoades, J.D., P.A. Raats, and R.J. Prather. 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soc. Am. J. 40:651-655.

Slavich, P.G. 1990. Determining EC_a-depth profiles from electromagnetic induction measurements. Aust. J. Soil Res. 28:443-452.