Soil Use and Management (1994) **10**, 55–60

The effect of different post-restoration cropping regimes on some physical properties of a restored soil

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Abstract. The aggregate stabilities of a soil restored after opencast mining and an undisturbed soil were measured over a complete cropping year from the time of ploughing a grass ley in autumn. This was to examine the effects of various post-restoration cropping regimes on soil aggregate stability and soil porosity. A wet sieving technique and a mild dispersion method were used to determine indices of soil macro- and micro-aggregate stability, respectively. Air filled porosity at field capacity and crumb porosity were also determined. Removal, storage and restoration decreased macro- and micro-aggregate stability. After restoration, the different grass managements i.e. cutting for silage and grazing, had similar effects on soil aggregate stability and maintained greater aggregate stability than the arable regimes. The pattern of fluctuation in soil macro-aggregate stability over the year was similar under all crops at both sites, but at the restored site there was a decline in stability, and differences in the air filled porosity at field capacity developed between cropping regimes. Micro-aggregate stability was less at the restored than at the undisturbed site and showed no seasonal variation or difference between cropping regimes. However, a difference in crumb porosity between cropping regimes did develop.

INTRODUCTION

SOILS restored after opencast coal mining have traditionally been sown with a grass ley as this helps to stabilize the weakened soil aggregates (Brook & Bates, 1960). Leys have beneficial effects on soil structural stability (Childs, 1942; De Boodt, 1979; Douglas *et al.*, 1986; Johnston, 1986; Haynes & Swift, 1990). Soil microbial activity under a grass ley plays a major role in aggregate stabilization, which is important for maintaining suitable structural conditions for

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cultivation and porosity for crop growth. However, fungal hyphae which are responsible for much of a soil's stability (Molope *et al.*, 1987) are less abundant in restored soils, especially where the soil has been stored for some years (Harris *et al.*, 1989). When a grass ley is ploughed there is usually a decrease in soil aggregate stability through oxidation of organic matter and disturbance of the habitats of stabilizing fungae and bacteria (Low, 1972). This decrease in stability may therefore be greater in a restored than in an undisturbed soil.

Decreased soil stability can lead to increases in bulk density because the matrix does not resist slaking, dispersion by water and the forces imparted by wheels, hooves and rainfall. This, in turn, leads to decreased aeration and water infiltration rate and the development of anaerobic conditions. Nitrogen losses by denitrification may follow.

There are many aspects of soil structure and numerous methods have been devised for its measurement (Dexter, 1988; Kay, 1990). Macro-aggregate stability is largely responsible for macro-porosity, which determines soil drainage rates and aeration; it changes seasonally and is often affected by cultivation and cropping regime (Kay, 1990). An air filled porosity of about 10% at field capacity is a minimum for successful crop growth (Dexter, 1988). Micro-aggregate stability is more resilient than macro-aggregate stability as the organic matter responsible for binding the soil particles together resides in pores too small for micro-organisms to occupy (Gregorich *et al.*, 1989). Micro-aggregates are less sensitive to cropping practices than macro-aggregates (Dexter, 1988), and are responsible for crumb porosity which controls the amount of plant available water.

We examined the effects of various post-restoration cropping regimes on changes in macro- and micro-aggregate stability during one season of arable cropping. Air filled porosity at field capacity and crumb porosity (Currie, 1966) were determined at the end of the season. The restored soil was compared with that from a nearby undisturbed site.

MATERIALS AND METHODS

Sites

The experiment compared a site restored early in 1986 after opencast coal mining (National Grid Reference: NU 238013) and an undisturbed site located 500 m away at Acklington in Northumberland. They were part of a larger study examining other aspects of land restoration after opencast coal mining. Both sites were located 30 m above sea level on clay loam stagnogleys of the Dunkeswick series (Jarvis *et al.*, 1984).

The restored soil profile consisted of three distinct horizons: a topsoil 25–30 cm thick above approximately 90 cm of subsoil over an overburden of grey shale and mudstone. The topsoil, subsoil and overburden, stripped from the original site, had been stored separately in mounds for seven years during the coal extraction period.

The soil at the undisturbed site consisted of Ap (0–25 cm), Eg (25–40 cm) and Btg (40–90 cm) horizons, all of which were well-structured; the peds were small subangular blocky in the Ap horizon and medium to coarse prismatic in the Eg and Btg horizons. The site had been in continuous arable cropping for a number of years prior to establishing the grass management for this experiment. Although the site could not be regarded as a control site, it served as a useful comparison. Limited space meant arable cropping was impossible at the undisturbed site.

Cropping regimes

Following restoration in 1986, the restored site was drained in August 1986 and both sites were ploughed between then and October. From October 1986 to October 1990, various cropping regimes were established; arable regimes were established at the restored site and grass was grown for silage and grazing at the restored and undisturbed sites. From October 1990 to October 1991, the sites were uniformly cropped with winter wheat.

Arable cropping. Three different regimes were started at the restored site in October 1986. In two of them the rotation was winter wheat, winter barley, winter barley and oilseed rape. In one of these the soil was deep ripped to below 50 cm during seedbed preparation in 1986 and 1988, and phosphate and potash fertilizer were incorporated by ploughing each autumn. In the other there was no deep ripping and phosphate and potash fertilizer were applied to the surface only. The third regime included green manure and was started in May 1987, when peas were sown. These were first macerated by flail and then incorporated into the soil in autumn 1987 by ploughing. The soil was left fallow over winter and then this cropping repeated until autumn 1990.

Grassland cropping. Grass regimes were started in May 1987 at both the restored and undisturbed sites. A perennial ryegrass/clover mixture was sown on four plots (15×33 m for silage and 30×33 m for grazing) at each site. Two were grazed continuously by sheep between April and September and two were cut for silage on three occasions between June and September. One of each of the silage and grazed plots received 200 kg N/ha per year and one received no fertilizer N.

This range of cropping regimes allowed subsequent comparisons of soil aggregate stability to be made under cut and grazed grass at both high and low nitrogen application rates, both within and across sites. Within the restored site, stability of soil aggregates under the continuous arable rotation was compared to those under the various grass and green manure regimes. Where comparisons were made between sites, identical management practices were used.

Sampling and analysis

Four soil sampling dates were selected for determination of macro- and micro-aggregate stability:

(1) August 1990 after a 3 yr post-restoration cropping period and before the grass swards were ploughed out;
(2) October 1990, after production of the seedbed for the 'test crop' of winter wheat;
(3) April 1991 after the winter period;
(4) October 1991 after production of the second seedbed.

Soil stability following ploughing of the grass sward was examined at the restored and undisturbed sites and compared to that following the arable regimes at the restored site.

Samples of topsoil (ploughing depth) were taken under various crops at each site. At both the restored and the undisturbed sites they were taken from grass plots under both silage and grazing regimes. At the restored site only they were taken from plots under the continuous arable and the green manure regime. Six 500 g samples of soil per plot were taken. After air-drying (this causes minor changes in stability (Hofman, 1976) but allows for easier handling and fractionation), the six were bulked into pairs for three determinations of macro-and micro-aggregate stability per plot.

In February 1992 another set of samples was taken, when the soil was at field capacity, to determine crumb (1–2 mm) porosity (Currie, 1966), air filled porosity at field capacity and bulk density (Avery & Bascomb, 1982) and infiltration rate (using a double ring infiltrometer) (Trout *et al.*, 1982). Particle size analysis, bulk density, available water capacity and organic matter content (Avery & Bascomb, 1982) were determined at the start of the experiment (Table 1).

Crumb or micro-aggregate porosity is a measure of the degree to which primary soil particles are held apart from the closest packing they might assume in an unstable, structureless soil; Currie (1966) showed that it varies with previous soil management.

Macro-aggregate stability

Macro-aggregate stability was determined on 5–16 mm aggregates using a wet sieving technique based on that of Yoder (1937). 100 g of air-dry aggregates of two size fractions, 5–8 and 8–16 mm, were placed together on a 4 mm sieve, which was fitted above a 2 and a 1 mm sieve. The air-dry aggregates were rapidly immersed in water as the three sieves were moved up and down mechanically for 20 minutes in a tank of water using a 4 cm stroke at 40 strokes per minute. The water level fluctuated about the aggregates on the top sieve. The wet sieving index (WSI) was determined three times for each cropping regime; it was calculated thus:

$$\left(\frac{5 \times \text{dry mass retained on 5 mm sieve}}{\text{total dry mass of soil used (150 g)}} \times 100\right)$$
$$+\left(\frac{2 \times \text{dry mass retained on 2 mm sieve}}{\text{total dry mass of soil used (150 g)}} \times 100\right)$$
$$+\left(\frac{1 \times \text{dry mass retained on 1 mm sieve}}{\text{total dry mass of soil used (150 g)}} \times 100\right)$$

The theoretical maximum and minimum values for WSI are 500 and 0, respectively.

Micro-aggregate stability

A mild dispersion technique adapted from Quirk (1950) was used to assess micro-aggregate stability. After air-drying and gently grinding the soil to avoid crushing stones, the aggregates 1–2 mm across were sieved out of the soil. Approximately 10 g of these were placed in a 0.5 dm^3 bottle and sprayed with a fine mist to minimize disturbance during the wetting process. After standing submerged for 1 h, the suspension volume was increased to 0.5 dm^3 and the bottles were shaken for 2 minutes on an end-over-end shaker. Suspensions were allowed to settle for the appropriate time as dictated by Stokes' Law, after which 0.02 dm^3 of the <20 μm fraction was removed using an Andreasen pipette and oven dried at 105 °C. The total dry mass <20 μm in the whole suspension was determined (MD). A separate sample was completely dispersed with hydrogen peroxide and sodium hexametaphosphate, and the dry mass of the <20 μm fraction determined as before (CD). The degree of aggregation (DA) was calculated:

$$\text{DA} = 1 - (\text{MD}/\text{CD})$$

Using this method a maximum value of '1' would indicate complete stability and a minimum value of '0' complete instability.

RESULTS

Macro-aggregate stability

The cropping regimes tested resulted in almost the maximum possible range of soil macro-aggregate stability (Fig. 1). All regimes showed seasonal variation with a decrease in macro-aggregate stability after ploughing of over 100 WSI units on the grass plots at both sites and about 50 WSI units on the arable plots. Over the winter period from October to April, macro-aggregate stability decreased further under all regimes at both sites; the smallest overall decrease was at the undisturbed site. For the grass regimes at each site, neither the rate of fertilizer N used nor the effect of cutting or grazing produced differences in aggregate stability. Aggregates under grass at the undisturbed site were more stable than those at the restored site. After ploughing, macro-aggregate stability on the arable plots declined rapidly during the subsequent winter period (Fig. 1). Aggregates in the deeply ripped regime had a WSI > 50% less than those in the conventionally cultivated regime ($P < 0.001$). By October in the second year, aggregate stabilities in the two

Table 1. Soil properties at the restored and undisturbed sites at the start of the post restoration cropping phase (standard errors in parentheses, $n = 4$)

	Restored		Undisturbed	
	Topsoil	Subsoil	Topsoil	Subsoil
Particle size distribution (weight %)				
Clay (<2 μm)	30.2 (0.76)	29.3 (1.19)	29.6 (1.13)	30.7 (0.57)
Silt (2–60 μm)	18.4 (0.35)	26.3 (0.81)	18.9 (0.42)	26.1 (0.20)
Sand (60–2000 μm)	51.4 (0.74)	44.4 (1.69)	51.5 (1.43)	43.2 (0.76)
Dry bulk density (t/m^3)	1.49 (0.07)	1.80 (0.09)	1.29 (0.09)	1.76 (0.04)
Available water capacity (volume %)	14.4 (1.1)	6.5 (0.5)	16.0 (0.6)	12.0 (0.7)
Organic matter (weight %)	3.76 (0.17)	3.17 (0.19)	5.13 (0.16)	2.80 (0.08)

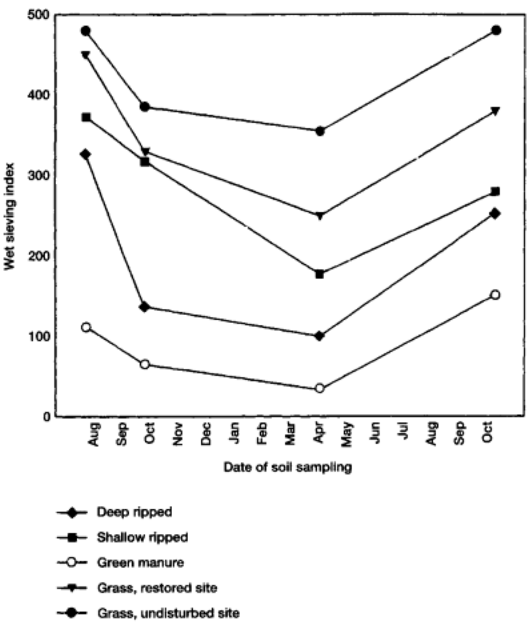

Fig. 1. Seasonal changes in soil macro-aggregate stability from the end of the post-restoration cropping phase to the beginning of the second year of the test crop (August 1990 to October 1991). Values for grass plots are means of the four regimes involved.

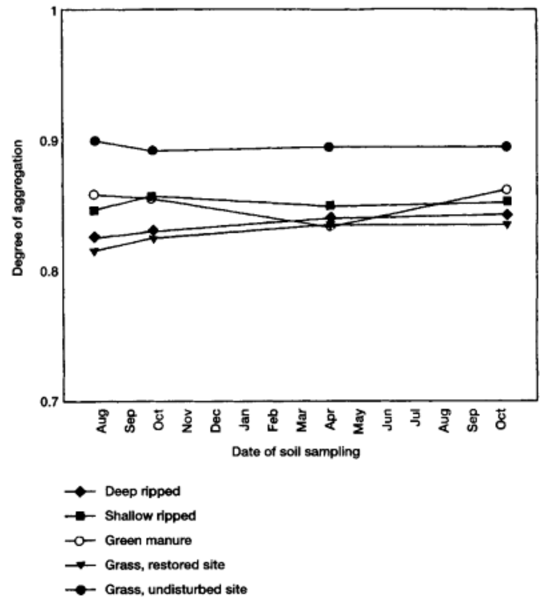

Fig. 2. Soil macro-aggregate stability from the end of the post-restoration cropping phase to the beginning of the second year of the test crop (August 1990 to October 1991). Values for grass plots are means of the four regimes involved.

arable regimes with the same crop rotation were similar. Macro-aggregate stability under the green manure regime was much less than under other regimes.

Micro-aggregate stability

The micro-aggregate stability under all cropping regimes showed no detectable change over the initial period from August to October. The mean value for the grass regimes was approximately 5% greater ($P<0.001$) at the undisturbed site (0.86) than at the restored site (0.82), and this difference remained throughout the experimental period, with no seasonal changes (Fig. 2).

Other soil properties

Under grass, air filled porosity at field capacity was 15% less ($P<0.001$) and infiltration rate 66% less at the restored than at the undisturbed site (Table 2). Air filled porosity was six times greater under the grass regimes than under other regimes at the restored site. For the two rotation arable regimes, air filled porosity at field capacity was very small (Table 2) with an average of 1%, although crumb porosity was not significantly less than the average for the grass regimes. The green manure plot had greater bulk density and smaller values for air filled porosity and infiltration rate than the grass plots and arable rotation, non-deep-ripped plot.

Mean crumb porosity under grass at the end of the experiment was approximately 15% greater at the undisturbed site than at the restored site.

DISCUSSION

In general, growth of grass during the 3 yr post-restoration period resulted in the greatest soil macro-aggregate stability (Fig. 1). The ploughing involved in the arable cropping regimes resulted in less aggregate stability than under the grass regimes at the restored site. Soil storage decreases the ability of the microbial population to function (Harris *et al.*, 1989), and this seems to have been reflected in the decreased aggregate stability at the restored site.

Macro-aggregate stability

Soil samples taken in October 1991 indicated that macro-aggregate stability had returned to pre-ploughing levels where grass had been grown at the undisturbed site but not where it was grown at the restored site.

Macro-aggregate stability under both plots which had previously grown arable crops in rotation did not reach pre-ploughing levels, and from August 1990 to October 1991 declined more than under the post-restoration grass regimes. Macro-aggregates on the green manure arable plot were always less stable than those of other regimes, but increased in stability after the plot was sown with wheat. Increased water extraction probably led to a drier, warmer and more aerated soil than under the green manure crop. Increased soil fungal and bacterial populations may then have resulted in the improved aggregate stability.

Micro-aggregate stability

Although soil micro-aggregate stability was in general unaffected by seasonal influences and the different post-restoration cropping regimes, soil storage may have been

Table 2. Topsoil (0–25 cm) physical properties during the second season of the test crop in February 1992, when the soil had reached field capacity (standard errors in parentheses, $n = 4$)

Post-restoration cropping regime	Dry bulk density (t/m³)	Air filled porosity (volume %)	Crumb porosity (volume %)	Infiltration rate (mm/h)
Restored site				
Arable 1†	1.35 (0.09)	2 (0.04)	28.1 (0.23)	11.5 (7)
Arable 2††	1.48 (0.12)	0 (0.07)	29.7 (0.60)	11.7 (8)
Green manure	1.43 (0.07)	4 (0.10)	28.9 (1.17)	10.0 (6)
Grass, silage 200N	1.36 (0.04)	9 (0.29)	27.4 (0.82)	29.3 (10)
Grass, silage 0N	1.37 (0.09)	8 (0.31)	29.8 (0.47)	50.4 (20)
Grass, grazed 200N	1.25 (0.07)	16 (0.52)	33.9 (0.23)	56.5 (17)
Grass, grazed 0N	1.32 (0.05)	14 (0.47)	31.9 (0.92)	23.4 (18)
Grass mean	1.33 (0.06)	12 (0.39)	30.8 (0.61)	39.9 (16)
Undisturbed site				
Grass, silage 200N	1.26 (0.07)	14 (0.88)	38.2 (0.91)	135.7 (38)
Grass, silage 0N	1.20 (0.02)	17 (1.09)	35.0 (0.68)	110.0 (45)
Grass, grazed 200N	1.21 (0.08)	10 (1.11)	33.8 (1.06)	126.6 (51)
Grass, grazed 0N	1.19 (0.11)	14 (1.28)	35.0 (0.23)	98.7 (49)
Grass mean	1.22 (0.07)	14 (1.09)	35.5 (0.72)	117.8 (48)

†Arable 1 not deep-ripped.
††Arable 2 deep-ripped.

responsible for the mean 5% less micro-aggregate stability at the restored site. During soil storage there seems to have been a decrease in the soil's micro-aggregate stability, which the most beneficial post-restoration cropping regime could only partly ameliorate. A 5% decrease in micro-aggregate stability is small in relation to the measured differences in macro-aggregate stability, but may have determined the maximum levels to which macro-aggregate stability could return.

Other soil properties

Deep ripping in one of the arable regimes brought substantial quantities of subsoil to the surface. This led to a significant increase in bulk density and to a slight decrease in an already small air filled porosity at field capacity because of contamination of the Ap horizon with denser subsoil.

Where grazed grass received 200 kg N/ha, crumb porosity increased to more than those of the other cropping regimes at the restored site. However, micro-aggregate stability did not follow this trend. Crumb porosity reflects the cumulative effects of management and cropping over a long period of time (Currie, 1966); the 3 yr post-restoration cropping period with grazed grass receiving 200 kg N/ha may have been long enough to improve crumb porosity, but was too short to detect any improvement in micro-aggregate stability. The decrease in micro-aggregate stability resulting from soil storage may have led to a decrease in crumb porosity to levels less than those achieved under typical agricultural regimes in the region.

Soil infiltration rate, which is largely determined by macro-aggregate stability, reflected to some extent the order of values for macro-aggregate stability between post-restoration managements. At the end of the study, soil infiltration rates on grass plots were at least four times greater than those under arable crops on the disturbed site. Waterlogging, surface runoff and the risk of excessive denitrification may all have been less on the plots initially restored with grass. However, the greatest infiltration rates at the restored site were still only approximately half of those recorded at the undisturbed site.

CONCLUSIONS

(1) Soil storage seems to have decreased macro- and micro-aggregate stability.
(2) Growing grass tended to promote the greatest macro-aggregate stability followed by arable cropping and then, much less, green manuring.
(3) The macro-aggregate stability of the soil after ploughing declined more rapidly in the restored than in the undisturbed soil.
(4) The resilience of micro-aggregate stability was little affected by seasonal influences and choice of crop.
(5) The effect on aggregate stability of soil storage during opencast mining may ultimately mean that cultivation is more difficult and crop growth less than on undisturbed soil.

ACKNOWLEDGEMENTS

We thank M. Holden, P. Shotton and W. Hewison for technical assistance and British Coal for funding the research.

REFERENCES

Avery, B.W. & Bascomb, C.L. 1982. *Soil Survey laboratory methods.* Soil Survey Technical Monograph **6**, Harpenden.
Brook, D.S. & Bates, F. 1960. Grassland in the restoration of opencast coal sites in Yorkshire. *Journal of the British Grassland Society* 15, 116–123.
Childs, E.C. 1942. Stability of clay soils. *Soil Science* **53**, 79–92.
Currie, J.A. 1966. The volume and porosity of soil crumbs. *Journal of Soil Science* 17, 24–35.
De Boodt, M. 1979. Soil conditioners for better soil management. *Outlook on Agriculture* **10**, 63–70.
Dexter, A.R. 1988. Advances in the characterisation of soil structure. *Soil and Tillage Research* **11**, 199–238.
Douglas, J.T., Jarvis, M.G., Howse, K.R. & Goss, M.J. 1986. Structure

of a silty soil in relation to management. *Journal of Soil Science* **37**, 137–151.
GREGORICH, E.G., KACHANOSKI, R.G. & VORONEY, R.P. 1989. Carbon mineralisation in soil size fractions after various amounts of aggregate disruption. *Journal of Soil Science* **40**, 649–659.
HARRIS, J.A., BIRCH, P. & SHORT, K.C. 1989. Changes in the microbial community and physico-chemical characteristics of topsoils stockpiled during opencast mining. *Soil Use and Management* **5**, 161–168.
HAYNES, R.J. & SWIFT, R.S. 1990. Stability of soil aggregates in relation to organic constituents and soil water content. *Journal of Soil Science* **41**, 73–83.
HOFMAN, G. 1976. The influence of drying and storing soil samples on aggregate instability. *Mededelingen Fakulteit Landbouwwetenschappen Fijksuniversiteit Gent* **41**, 101–108.
JARVIS, R.A., BENDELOW, V.C., BRADLEY, R.I., CARROLL, D.M., FURNESS, R.R., KILGOUR, I.N.L. & KING, S.J. 1984. *Soils and their use in Northern England*. Soil Survey of England and Wales. Bulletin **10**, Harpenden.
JOHNSTON, A.E. 1986. Soil organic matter, effects on soils and crops. *Soil Use and Management*, **2**, 97–105.
KAY, B.D. 1990. Rate of change of soil structure under different cropping systems. In: *Advances in Soil Science* **12** (ed. B.A. Stewart), Springer-Verlag, New York, pp. 1–52.
LOW, A.J. 1972. The effect of cultivation on the structure and other physical characteristics of grassland and arable soils. *Journal of Soil Science* **23**, 363–380.
MOLOPE, M.B., GRIEVE, I.C. & PAGE, E.R. 1987. Contributions by fungi and bacteria to aggregate stability of cultivated soils. *Journal of Soil Science* **38**, 71–78.
QUIRK, J.P. 1950. The measurement of stability of soil micro-aggregates in water. *Australian Journal of Soil Research* **1**, 276–284.
TROUT T.J., GARCIA-CASTILLAS, I.G. & HART, W.E. 1982. *Soil-water engineering. Field & laboratory manual.* Department of Agricultural and Chemical Engineering, Colorado State University.
YODER, R.E. 1937. The significance of soil structure in relation to the tillage problem. *Soil Science Society of America Proceedings* **2**, 21–33.