MECHANICAL AND HYDROLOGICAL PROPERTIES OF TWO OHIO MINED SOILS TWENTY-FIVE YEARS AFTER RECLAMATION[1]

M. K. Shukla[2], R. Lal, J. F. Underwood and M. H. Ebinger

Abstract. Surface mining results in extreme changes in soil properties. Reclamation plus natural pedogenesis over time gradually restores quality of drastically disturbed soil. The temporal changes in soil mechanical and hydrological properties were assessed for two reclaimed mined soils in Jackson (Fairpoint, FP soil) and Vinton (Bethesda, BT soil) counties in southeastern Ohio. The study was undertaken on three land uses viz.: (1) undisturbed soil (unmined; UMS), (2) reclaimed mined soil (RMS), and (3) spoil (SP). The UMS and RMS were under continuous tall grass cover since 1975-76 for both FP and BT locations. Soil fertility treatments imposed from 1979-1994 were studied for each RMS for three rates of nitrogen, phosphorous and potassium application 0-0-0 (FL1), 112-25-46 kg ha^{-1} (FL2), and 224-49-92 kg ha^{-1} (FL3). Soil development was clearly evident from the increase in the depth of Ap horizon, soil organic carbon (SOC) pool, clay eluviation, total porosity, effective porosity, available water capacity, water stable aggregation (WSA), total infiltration (I), sorptivity (S), and decrease in bulk density (ρ_b). The SOC pool for RMS in 0 to 10 cm of the Ap horizon increased from 14.2 Mg ha^{-1} in 1981 to about 28.7 Mg ha^{-1} in 2001 for FP soil and from 15.1 Mg ha^{-1} to 30.2 Mg ha^{-1} for BT soil. Fertility treatments decreased mean ρ_b by 9% for 0 to 10 cm depth and 5% for 10 to 20 cm depth for FP soil, and by 4% for only 0 to 10 cm depth for BT soil. The average values of WSA and mean weight diameter (MWD) were in the order UMS > RMS> SP for both FP and BT soils. The magnitude of clay eluviation between 1981 and 2001 was about 26% for 0 to 10 cm depth and 16 % for 10 to 20 cm depth for FP soil, and 8% for 0 to 10 cm depth for BT soil. The high S and I values for RMS and UMS land uses indicated that together with natural pedogenesis, macropore channels formed by roots also had a significant impact on water transmission properties.

Additional Key Words: Drainable porosity, Available water content, Soil bulk density,

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Introduction

The total land area of the United States (excluding Alaska and Hawaii) comprises 917 million ha, with approximately 57% devoted to agricultural land use. The total mined area in US between 1930 and 1971 was approximately 1.5 Mha, which was < 0.2% of total land area (Paone et al., 1978). The total land area of Ohio is approximately 7.6 Mha, of which nearly 35% is agricultural land (Frey, 1973). The total mined area in Ohio ranges from 0.29 to 0.32 Mha (AMLSF, 2000).

Mining is defined as "the process or activity aimed at removing a desired mineral from it's natural placement in the earth" and can be either surface or underground (Box, 1978)". Three terms relevant to post mining operations are: restoration, reclamation, and rehabilitation. Restoration is defined as "the replication of exact conditions of site after the completion of mining process as before disturbances". Reclamation implies "rehabilitation of the same organisms or species in approximately the same density and composition as originally present". Rehabilitation means "return of disturbed site to a form and productivity in conformity with a prior land use" (NAS, 1974; Box, 1978).

Soil degradation can occur by both natural and anthropogenic perturbations. Surface mining is an anthropogenic activity, which drastically changes the antecedent soil profile, and physical, chemical and biological properties and processes (McSweeney and Jansen, 1984; Lal, 1997; Shukla et al., 2003a). Soil degradation leads to loss of soil organic carbon (SOC) concentration mainly as a result of high mineralization, erosion and leaching (Lal et al., 1998; Akala and Lal, 2001), loss of structure (Jansen, 1981), increase in bulk density (ρ_b) (Chong et al., 1986; Underwood and Sutton, 1992; Guebert and Gardner, 2001), and reduction in porosity (Silburn and Crow, 1985).

In mid to upper Eastern Appalachian areas, a focus of several studies has been on soil development over time in surface mined areas (Underwood and Smeck, 2002). There are differing opinions about the rate of mined soil development. However, there is a consensus that the initial high soil weathering decreases rapidly over time (Struthers, 1964). The spoil material is subjected to rapid weathering, and changes in chemical properties and particle size distribution (Van Lear, 1971). Mine spoil represents the properties of parent material and the rate of mined soil development over time may be an important edaphic factor representing the degree of mined soil development (Akala and Lal, 2001). Minor changes in soil morphology especially in Ap horizons occurred within 5 years after reclamation in western Kentucky, whereas major changes were observed 10 to 21 years after reclamation (Barnhisel and Gray, 2000). Deeper root growths and weaker grades of soil structure were reported in some studies in northern West Virginia (Smith et al., 1971). Distinct organic matter enrichment eight years after reclamation was reported for southwestern Virginia (Haering et al., 1993; Thomas et al., 2001). In some reclaimed soils under different land uses in Ohio, there was a substantial increase in the soil organic carbon (SOC) pool after 25 years of topsoil application (Akala and Lal, 2001; Shukla et al. 2003a). The increase in infiltration rates and total infiltration in the first year after tillage and decline in subsequent years in reclaimed mined soils in Perry County, IL was reported by Chong and Cowsert (1997).

Soils are complex and dynamic systems, the rooting depth and the soil needs are often site-specific functions of climate, land use and management options. The reclamation materials are also unique and site-specific (Jansen, 1981). The ultimate goal is to reconstruct the reclaimed site in a manner that maximizes the rate of soil improvement over time (Jansen, 1981). Such goals warrant site-specific investigations designed to study temporal changes in soil properties after reclamation (Barnhisel and Hower, 1997).

This study was designed to investigate changes in soil mechanical, hydrological and chemical properties of reclaimed soils in relation to the undisturbed native (unmined) soils. The main hypothesis was that reclamation improves soil structure, which can be inferred from the higher water infiltration (I), available water capacity (AWC), drainable porosity (f_a), effective porosity (f_e), and SOC concentration as compared to an unreclaimed mined soil or spoil (SP). The secondary hypothesis was that aggregation is influenced by the silt plus clay concentration of the soil, and soil development progresses with increased SOC sequestration and clay eluviation. The specific objectives of this study were to: (1) evaluate the magnitude of soil development in mined soils under continuous forage cover from 1981 to 2002, (2) determine the influence of mining and reclamation activities on soil structural and mechanical properties, (3) estimate SOC pool and its rate of change since 1981, and (4) evaluate the influences of soil fertility treatments on yield and quality of forage.

Methods and Materials

Site Descriptions

Studies were conducted at two surface mined sites that were reclaimed in 1975-76 after coal removal. The sites were located near Jackson (Jackson County) and McArthur (Vinton County) in southeastern Ohio. The exact position of the experimental plots near Jackson was between $38^{o}54'49"$ and $82^{o}32'11"$ and near McArthur between $39^{o}17'03"$ and $82^{0}26'13"$. The average annual precipitation for the study area is 1090 mm, with more than 50% (i.e. 530 to 580 mm) occurring during May through September. Average annual temperature of the study area is 11^{o} C. The mined soil at Jackson was originally classified as loamy-skeletal, mixed, nonacid, mesic, Typic Udorthent and is called Fairpoint (FP) series. The soil at McArthur was classified as loamy-skeletal, mixed, acid, mesic, Typic Udorthent and is called Bethesda (BT) series. Pedogenesis since 1981 by the development of a Bw horizon, the BT site is now classified as Dystric Eutrudept. Development of CB horizon (at the FP) now classified as Typic Eutrudept (Underwood and Smeck, 2002). Nearby UMS sampled at the FP site is classified as Amoulga silt loam (Typic Fragiudalfs), and at BT as Wordon silt loam (Aquic Hapludults). Both are believed to typify soils in the mined areas before disturbance (Kerr, 1985).

Management Options

There were 36 small plots, each of 18 m^2 (6 m X 3 m) area, laid out according to a randomized complete block design at both sites. The original experiment involved nine different fertilizer treatments (N-P-K combinations) with four replications initiated in the spring of 1979 and continued through 1994 (Underwood and Sutton, 1992). The present study involved three land uses at each site: (1) undisturbed soil (unmined; UMS), (2) reclaimed minesoil (RMS), and (3) spoil (SP) (Table 1). There were three soil fertility treatments studied here for RMS: (i) no fertilizer or 0-0-0 kg ha^{-1} (or FL1), (ii) 112-25-46 kg ha^{-1} (or FL2) and (iii) 224-49-92 kg ha^{-1} (or FL3) (Table 1). All treatments were replicated four times. The experimental plots in RMS were seeded to a mixture of clovers (*Trifolium* spp.) and cool-season grass species in 1975, but tall fescue (*Festuca arundinacea* Shreb.) has been the dominant specie in all plots for FP and BT soils. The SP was the study of the upper spoil material, 25 to 35 cm beneath the soil surface. The UMS and RMS for both locations were under continuous forage cover since reclamation.

Table 1. List of treatments under investigation for experimental sites in FP and BT soil (four samples were collected from each depth for each treatment)

No.	Treatment	Fertilizer rate kg ha^{-1}	Forage	Soil Depth cm
1	Unmined Soil (UMS)	-	Continuous Pasture	0-10
2	Spoil (SP)	-	-	25-35
3	Soil Fertility treatment 1 (FL1)	0-0-0	Forage grass + legume	0 to 10 10 to 20
4	Soil Fertility treatment 2 (FL2)	112-25-46	Forage grass + legume	0 to 10 10 to 20
5	Soil Fertility treatment 3 (FL3)	224-49-92	Forage grass + legume	0 to 10 10 to 20

Soil sampling and Pedon Location

Bulk and core soil samples were obtained in 2001 for determination of soil mechanical and hydrological properties. Four samples were collected from each of the five treatments (Table 1) at both locations for 0 to 10 cm depth. Additional soil samples for 10 to 20 cm depth were obtained from soil fertility treatment plots in RMS at both locations (Table 1). Soil samples were obtained during the month of December 2001 from RMS and May 2002 from UMS at both sites. Soil properties measured included bulk density (ρ_b), total porosity (f_t), drainable porosity (f_a), effective porosity (f_e), available water capacity (AWC), soil moisture characteristics, total infiltration (I), and SOC concentration, and pool. Soil profiles were excavated for a depth > 75 cm in 1981 and again in 2001, to assess the thickness of different horizons, and evaluate the progress of soil development (Underwood and Smeck, 2002).

Bulk Density and Porosities

Soil ρ_b was determined by the core method using 7.5 cm long and 7.5 cm diameter cores (Blake and Hartge, 1986). The f_t was calculated from the measured values of ρ_b and assumed particle density value of 2.65 Mg m^{-3}. Soil moisture characteristic curves were determined on intact soil cores for 1 kPa, 3 kPa, and 6 kPa suctions using the tension table (Leamer and Shaw, 1941), and for 10 kPa, 30 kPa, 100 kPa, and 300 kPa suctions using the pressure plate apparatus (Richards, 1947; Klute, 1986). Water content at 1500 kPa was determined using ground and sieved soil samples (< 2mm). The difference in volumetric moisture content (θ) at saturation and 6 kPa was defined as f_a, and that between saturation and 10 kPa as f_e (Ahuja et al., 1984). The AWC was assessed as the difference in θ at 300 kPa and 1500 kPa suction, expressed in equivalent depth of water for the specific soil layer.

Water Stable Aggregation, Particle Size Distribution and Soil Organic Carbon Concentration

The bulk soil samples were air-dried and sieved through nested sieves (8, 5 and 2 mm). About 80 to 100 g of aggregates retained on the 5 mm sieve were separated for the determination of the water stable aggregates (WSA) and mean weight diameter (MWD) by the wet sieving technique (Yoder, 1936; Youker and McGuinness, 1957). The sieved sample (< 2 mm) was used for the determination of particle size distribution by the hydrometer method (Gee and Bauder, 1986). About 100 g of the soil retained on the 5 mm sieve and that < 2mm was ground to pass through 0.5 mm sieve prior to C analysis. The total carbon (TC) was obtained by the dry combustion method (Nelson and Sommers, 1986), and was converted to SOC using eq.[1] of Lal et al. (1998) for a specific layer of thickness 'd'.

$$\text{Mg C ha}^{-1} = [\text{\% C X corrected } \rho_b \text{ (Mg m}^{-3}) \text{ x d (m) x } 10^4 \text{ m}^2 \text{ ha}^{-1}]/100 \qquad (1)$$

Total Infiltration, Soil Water Sorptivity, and Equilibrium Infiltration Rate

Ponded water infiltration tests were conducted in June 2002 on the soil surface using tap water and a double ring infiltrometer with 27 cm diameter of the outer ring and 15 cm diameter of the inner ring (Bouwer, 1986). The water infiltration tests were conducted for 150 minutes. The antecedent volumetric water content of the soil (θ_0) and the water content 24 h after the infiltration experiment, assumed to be field capacity (FC), were also determined. The sorptivity (S, cm $min^{-0.5}$) and equilibrium steady state infiltration rates (i_c, cm min^{-1}) were computed by the Philip (1957) model.

Forage Yield and Composition

The forage was harvested during June 2002 and dry matter yield was calculated for each of the soil fertility treatments for both RMS sites. A representative air-dried forage sample was analyzed for nitrogen (N) by macro-N analysis (AOAC, 1990), and P, Na, K, Ca, and Mg concentrations by plasma emission spectroscopy (Isaac and Johnson, 1985).

Statistical Analysis

The analysis of variance (ANOVA) was computed using the randomized block one-factor design (OFD) using the Statistical Analysis System (SAS Institute, 1989). The ANOVA was also computed separately for forage yields, N, P, and K concentrations in forage, and soil structural and water transmission properties for three soil fertility treatments for 10 to 20 cm depth. The data for each soil depth was analyzed separately. Significant interactions ($P \leq 0.05$) and the least significant differences (LSD) for mean separation were calculated by comparing reclamation activities (treatment X replicate) and fertility treatment (treatment X replicate) within each site.

Results and Discussion

Soil Horizon Development

There was a distinct horizon development and formation of soil structural units in both mined soils. The structure evolved from weak, moderate subangular blocky to weak, very fine subangular blocky in FP soil, and from strong medium platy to moderate fine granular in BT soil (Underwood and Smeck, 2002). Some changes in structure and/or consistency were observed up to 50 cm depth in FP and 40 cm in BT. In general the structure below 20 to 25 cm depth was weak medium and coarse subangular or angular blocky for both soils (Underwood and Smeck, 2002).

Soil texture is a function more of pedogenic than management factors. According to the USDA classification, soil texture was “silt loam” for both soils. A comparison of the particle size distribution for soil sampled in 1981 and 2001 for RMS indicated a marked degree of clay eluviation for both soils (Table 2). The loss in clay over the 20-year period from 1981 to 2001 was 26% for 0 to 10 cm depth and 16 % for 10 to 20 cm depth for FP soil (Table 2). In comparison, clay concentration decreased 8% for 0 to 10 cm depth, but slightly increased in 10 to 20 cm for BT soil. The clay eluviation from 0 to 10 cm depth may be due to the development of the Ap horizon in both soils.

Table 2. Morphological and physical properties of reclaimed FP and BT soils. The horizons are listed for FL1, FL2 and FL3 treatments (Underwood and Smeck, 2002; Shukla et al., 2003a)

Horizon	Depth cm	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	ρ_b Mgm^{-3}	SOC Pool $Mgha^{-1}$
			5 year old FP soil 1981			
Ap	0-10	179	571	250	1.65	14.2
C	>10	302	496	202	1.89	NA
			26 Year old FP soil 2001			
Ap1	0-10	291	529	181	1.54	31.3
Ap1	0-10	286	540	174	1.49	27.3
Ap1	0-10	266	541	193	1.48	27.6
Ap2	10-20	307	535	158	1.82	11.0
Ap2	10-20	302	524	174	1.76	9.8
Ap2	10-20	299	526	175	1.80	13.3
			5 year old BT soil 1981			
A	0-10	262	565	173	1.74	15.1
C1	10-20	441	402	157	1.73	NA
			26 Year old BT soil 2001			
Ap1	0-10	354	486	160	1.61	29.4
Ap1	0-10	314	517	169	1.89	36.3
Ap1	0-10	388	465	148	1.53	25.0
Ap2/Bw	10-20	249	566	184	2.07	22.3
Ap2/Bw	10-20	314	515	171	1.98	18.9
Ap2/Bw	10-20	448	408	144	1.83	13.8

NA- not available

Soil Organic Carbon Pool

The SOC pool in RMS for the upper 0 to 10 cm of the Ap horizon increased from 14.2 Mg ha^{-1} in 1981 to about 28.7 Mg ha^{-1} in 2002 for FP soil, and from 15.1 Mg ha^{-1} to about 30.2 Mg ha^{-1} for BT soil (Table 2). Treatments had a significant impact on the SOC pool for both soils (Figs. 1 and 2), and were in the order UMS>RMS>SP (Shukla et al., 2003a). The highest SOC of 65.9 Mg ha^{-1} was obtained for UMS for BT.

Soil Mechanical and Hydrological Properties

Treatments had a significant impact on soil ρ_b. The ρ_b of reclaimed FP soil was 1.65 Mg m^{-3} for 0 to 10 cm depth in 1981, which was 12 % higher than that of the UMS (Table 2; Shukla et al., 2003a). The ρ_b of RMS for FP decreased from 1.65 Mg m^{-3} in 1981 (Underwood and Smeck,

2002) to 1.50 Mg m^{-3} in 2001 for 0 to 10 cm depth (Shukla et al., 2003a). For 10 to 20 cm depth, the ρ_b of FP decreased from 1.89 Mg m^{-3} in 1981 to 1.80 Mg m^{-3} in 2001.

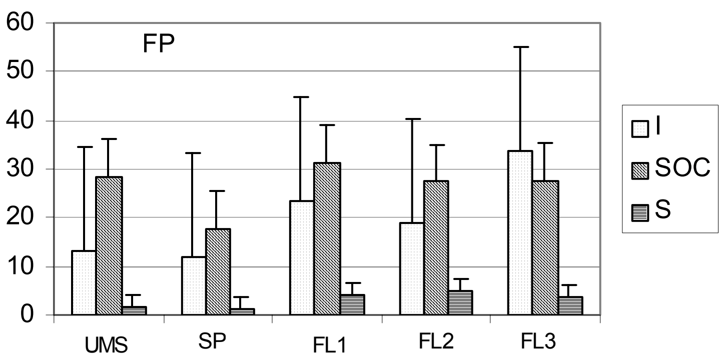

Fig. 1. Land use and management effects on total infiltration (I, cm), soil organic carbon pool (SOC, Mg ha^{-1}), and soil water sorptivity (S, cm min$^{-0.5}$) for FP soil

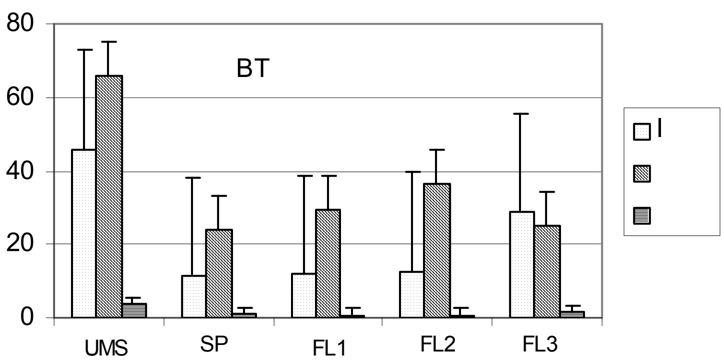

Fig. 2. Land use and management effects on total infiltration (I, cm), soil organic carbon pool (SOC, Mg ha^{-1}), and soil water sorptivity (S, cm min$^{-0.5}$) for BT soil

The ρ_b of BT was 1.74 Mg m^{-3} for RMS in 1981, which was about 11% higher than that of the UMS. The ρ_b of RMS for BT decreased from 1.74 Mg m^{-3} in 1981 to about 1.67 Mg m^{-3} in 2001 for 0 to 10 cm depth. However, ρ_b increased over the same period for BT for 10 to 20 cm depth. Reclamation treatments decreased ρ_b by 9% for 0 to 10 cm depth and by 5% for 10 to 20 cm depth for FP soil, and 4% for 0 to 10 cm depth for BT soil. The decrease in ρ_b was in accord with the observed structural improvement and increase in SOC concentration.

Treatments also had significant influence on WSA and MWD for both soils (Shukla et al., 2003a). The average WSA ranged from 850 to 950 g kg^{-1} for UMS compared with only 210 to

230 g kg^{-1} for SP of the FP soil. Similarly, the average WSA was larger for UMS (700 to 870 g kg^{-1}) than SP (310 to 350 g kg^{-1}) for BT soil (Shukla et al., 2003a). The average WSA and MWD for 0 to 10 cm depth were higher than those for 10 to 20 cm of RMS for both sites and were in accord with the development of Ap horizon and resultant reduction in ρ_b.

The soil water characteristic curves (SWC) showed large standard deviations of θ for SP and RMS for both soils, except for FL3 in FP and FL1 in BT soil (Figs. 3 and 4). The standard deviations of θ were much smaller for UMS for both soils, which showed that the soil in UMS was more uniform than in RMS. Treatments also influenced porosity and AWC for both soils (Figs. 5 and 6). The highest f_t of 66% was recorded for the UMS and the lowest of 44% for SP. The f_a and f_e were in the order UMS>RMS>SP for both soils. The AWC for both soils was also in the order UMS>RMS>SP. The higher porosities for RMS were in agreement with the observed decrease in soil ρ_b between 1981 and 2002 (Table 2). The silt plus clay concentration in RMS for both FP and BT soils was higher than that in SP, and that may have contributed to the higher WSA in RMS than SP (Attou et al., 1998; Shaver et al., 2002; Shukla et al., 2003b). The higher AWC in UMS and RMS than in SP may be the consequence of higher porosity, aggregation, and SOC concentration in the respective treatments.

Water Transmission Properties

Treatments significantly influenced cumulative water infiltration (I) (Figs. 1 and 2; Shukla et al., 2003a). The highest I of 34 cm was measured in the FL3 and the lowest of 12 cm in the SP for FP soil. In comparison, the highest I of 46 cm was measured in the UMS and the lowest of 24 cm in the SP for BT soil. The I was in the order RMS>UMS>SP for FP soil, and UMS>RMS>SP for BT soil (Shukla et al., 2003a). The higher I from RMS than SP was in accord with the higher values of f_t, f_e, and AWC. In addition to the ameliorative effects of natural pedogenesis, macropores formed by roots may also have contributed to large I. Higher I values for RMS observed 4 to 9 year after reclamation were also reported by Jorgensen and Gardner (1987); Guebert and Gardner, (2001); Shukla et al., (2003a).

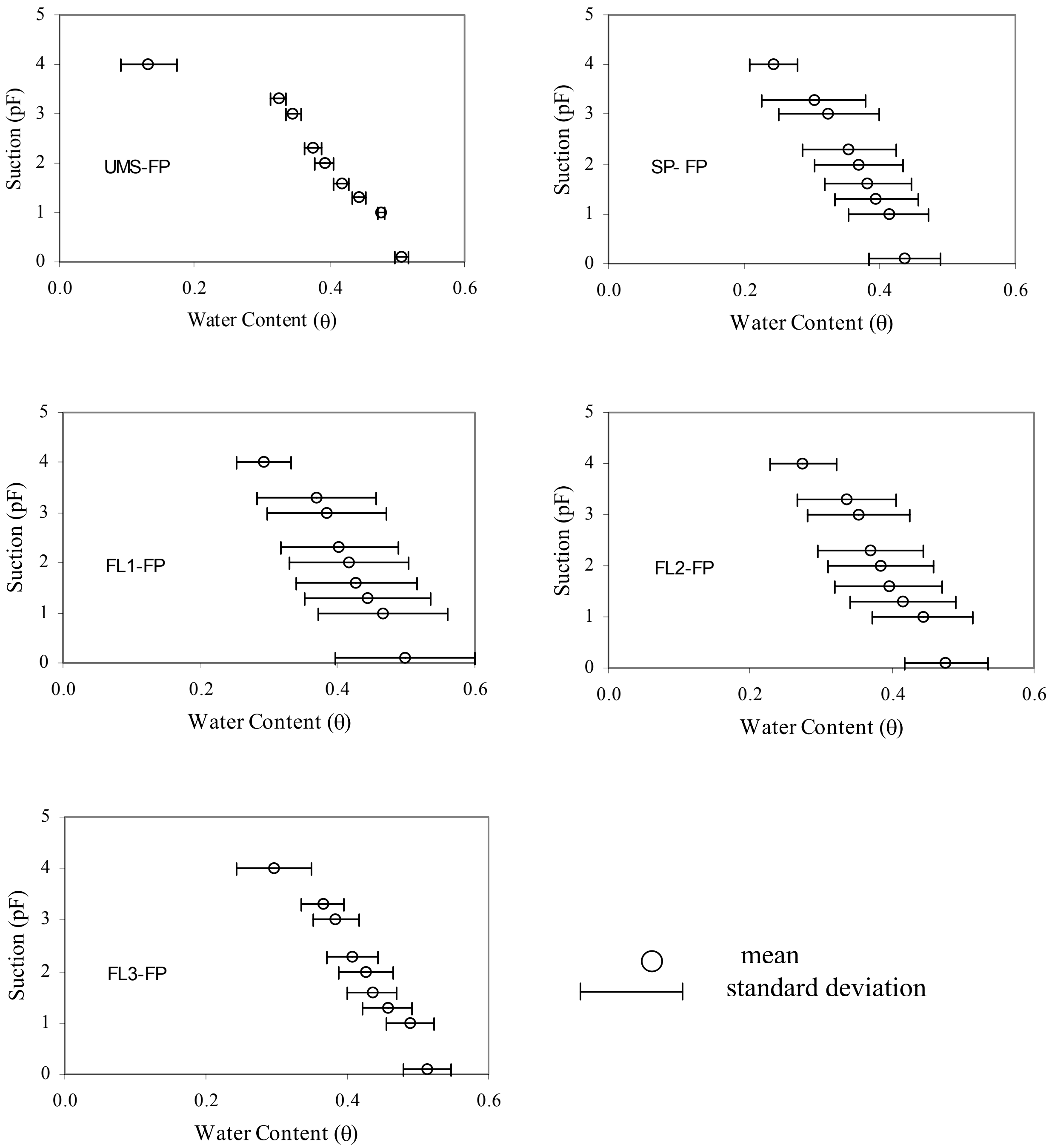

Fig. 3. Treatment effects on the mean and standard deviations of soil water content (θ) at different suctions for FP soil.

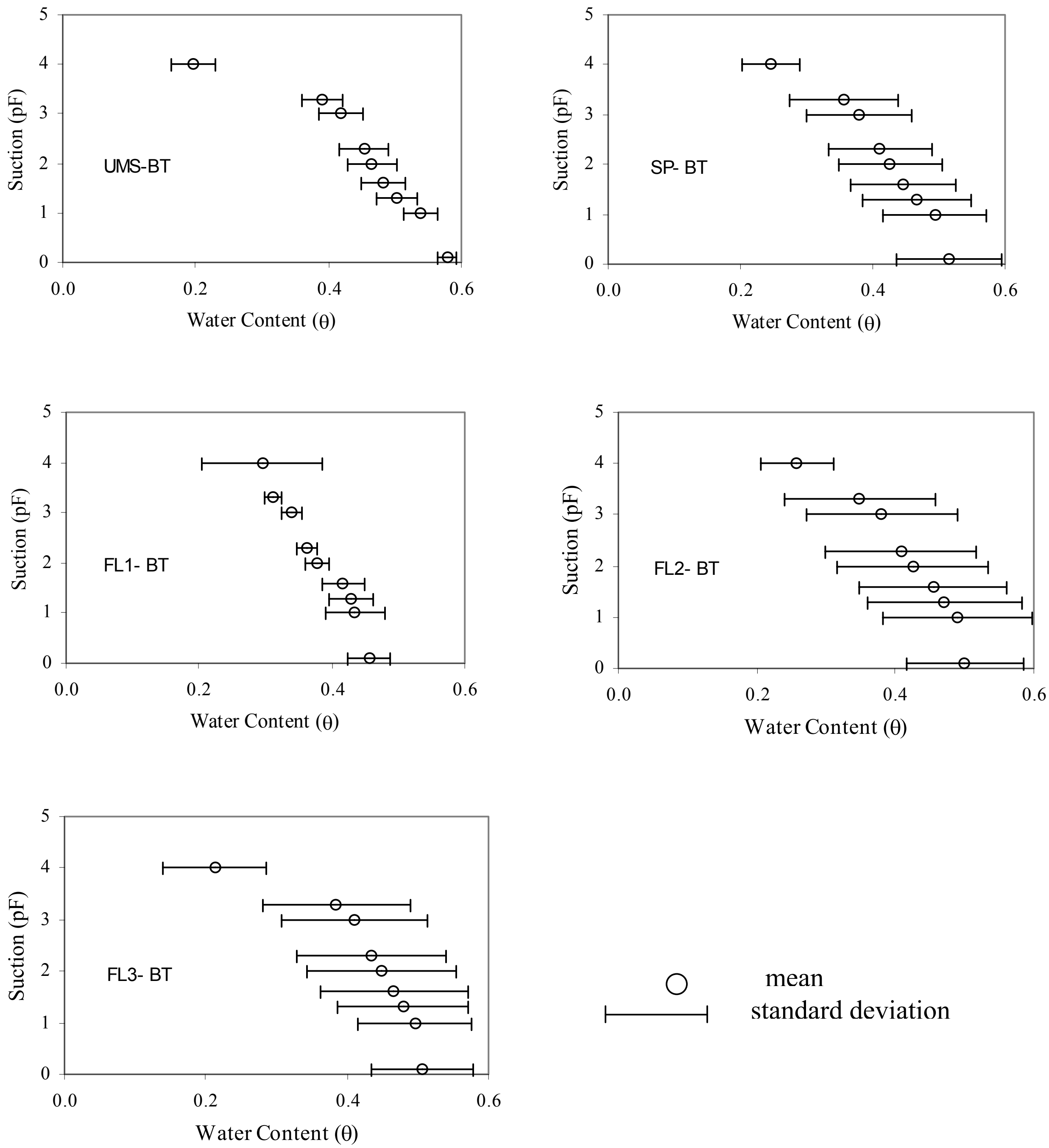

Fig. 4. Treatment effects on the mean and standard deviations of soil water content (θ) at different suctions for BT soil.

Treatments have significant impact on S for both soils (Figs. 1 and 2). The highest fitted S of 4.97 cm min$^{-0.5}$ was obtained for FL2 and the lowest of 1.38 cm min$^{-0.5}$ for SP for FP soil. In comparison, the highest fitted S of 3.59 cm $min^{-0.5}$ was recorded for the UMS, whereas the lowest of 0.75 cm $min^{-0.5}$ for the FL2 for BT soil (Fig. 1 and 2). Similarly, fitted transmissivity (A) values from Philip (1957) model were significantly correlated with S values and explained about 64% of variability in S across all treatments for FP soil. However, several negative values of A indicated the lack of applicability of Philip (1957) model on the I(t) dataset.

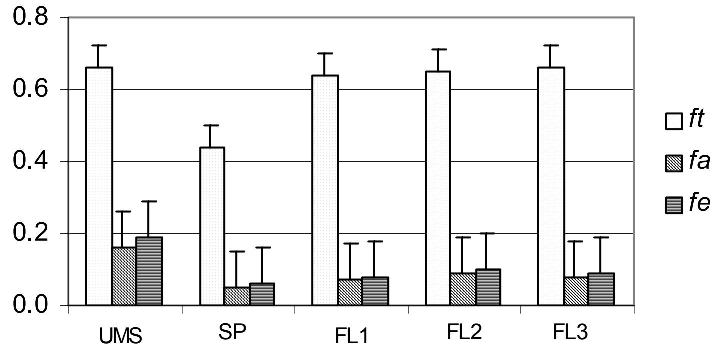

Fig. 5. Treatment effects on porosity (*ft*- total, *fa*- drainable and *fe*- effective) characteristics for FP soil (UMS is unmined soil, SP is spoil, FL1, FL2, and FL3 are fertility treatments in RMS)

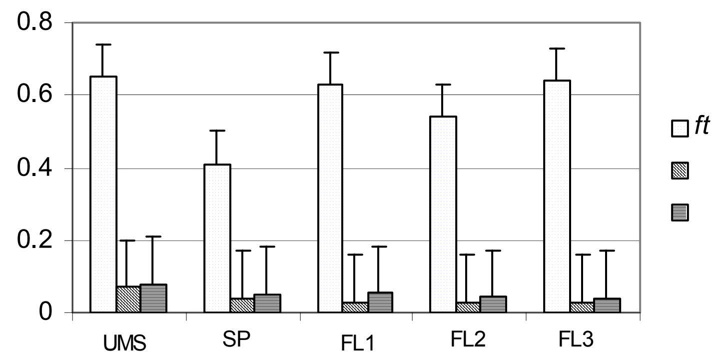

Fig. 6. Treatment effects on porosity characteristics for BT soil

The correlation coefficient between the fitted S and A was insignificant (r^2<0.01) for BT soil, and those between S and measured saturated hydraulic conductivity (K_s) (Shukla et al., 2003a) was also insignificant for both locations (r^2<0.1). Correlation coefficients between the fitted S and the measured f_e were insignificant for FP soil, but 33% of the variability in f_e was attributed to that of S for BT soil. The low correlation coefficients observed between fitted S and K_s or f_e

indicated that the S was not the true sorptivity of the soil matrix and was influenced by biopores (Shaver et al., 2002; Shukla et al., 2003b). Measured K_s or f_e are determinants of S, because cores generally exclude root channels draining large quantities of water at relatively small suctions.

Forage Productivity and Quality in Relation to Fertilizer Treatments

Soil fertility treatments did not have a significant impact on June 14, 2002 forage yields in RMS for either soil. The FP soil was non-acidic with mean soil pH of 7.7, whereas BT soil was slightly acidic with mean pH of 6.6 in RMS (Shukla et al., 2003a). A higher pH supports root development, and above ground biomass (Haynes and Naidu, 1998). The more favorable pH at FP compared to BT soil was reflected in the quantity and quality of forage. Higher forage dry matter yields, (2592 versus 2029 Kg ha^{-1}) may be due to the presence of 23% of legumes at the FP site compared to 0.7 % at the BT soil. The average N concentration in forage was 1.60% for FP compared with 1.21% for BT, resulting in a difference in the estimated crude protein concentration of 2.5%. Predominant forage legumes included red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.), black medic (*Medicago lupulina* L.) and small hop clover (*Trifolium dubium* Sibth).

Soil fertility treatments had a significant impact on N, P, K and total concentrations of cations (CC) in forage for FP soil (Fig. 7). Fertility treatments had a significant impact on the concentrations of P, K and CC but not on N for BT soil (Fig. 8).

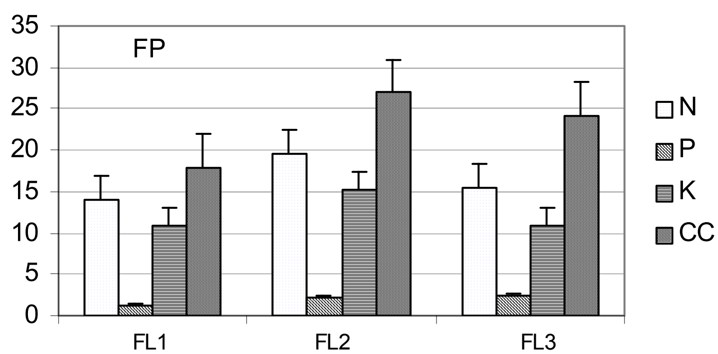

Fig. 7. Treatment effects on forage tissue elemental concentration for Fairpoint (FP) soil (FL1, FL2, FL3- fertility treatments 1, 2 and 3, respectively; CC is total concentration of cations)

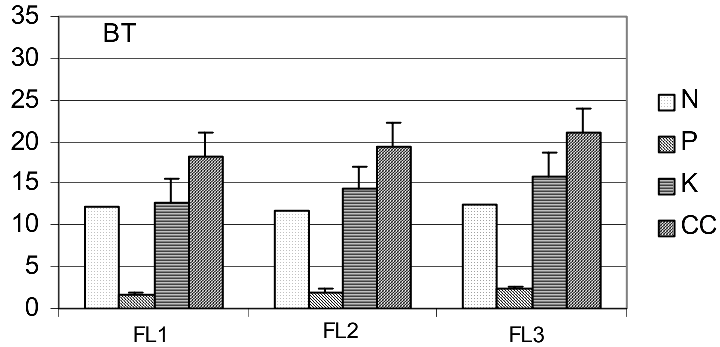

Fig. 8. Treatment effects on forage tissue elemental concentration for BT soil

A high residual P level from annual fertilizer application produced the highest forage yield in FL3 treatment at the BT site. The concentration of P in forage for both sites, however, was significantly higher in FL3 plots compared to FL1 and FL2 treatments.

Conclusions

Reclamation treatments significantly and positively influenced soil structure, and water retention and transmission parameters. Soil reclamation with fertilizer application improved soil structure. Soil development was evident by increases in the depth of the Ap horizons, WSA, MWD and I, and attendant decrease in ρ_b. The SOC concentration of reclaimed mined soil also increased indicating a large potential of C sequestration through conversion to a restorative land use and improved management practices.

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