INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2000/02–3–264–268

Reveiw
Application of Soil Physics for Sustainable Productivity of Degraded Lands

ANWAR-UL-HASSAN
Department of Soil Science, University of Agriculture, Faisalabad–38040, Pakistan

ABSTRACT

Soil surface crusting and compaction are physical soil management problems. Soil crusting is a very serious problem in Pakistan (common in many arid and semi-arid region soils) due to deficiency of organic matter and/or presence of high sodium and silt contents. Effect of subsoil compaction on reduction in yield of crops and nutrient uptake is more serious than that of surface-compacted soils. Most of the research work carried out on crusting is in rainfed areas of Pakistan. Crusting reduces seedling emergence and the penetration of water into soils. The most common methods to control crusting are use of mulch and addition of organic matter or gypsum to reduce soil dispersion. Hoeing is generally the best treatment for managing crust in the soil. Performing tillage operations at optimum water contents and/or including deep tillage operations in seedbed preparation after every two years can control soil compaction.

Key Words: Degraded lands; Sealing; Crusting; Compaction; Plough plan

INTRODUCTION

Soil compaction and surface crusting or sealing are important types of physical soil degradation. Compaction is often caused by excessive traffic or loading, especially when soils have high water contents. Soil compaction can be surface or subsurface or may be in the form of a pan, all forms reduce the total pore space and pore-size, resulting in increased bulk density. High bulk density (BD) of soils decreases water infiltration through soils, and the rate as well as amount of root penetration. Due to repeated cultivation of soils to the same depth (7-8 cm), compact layers called plough pans are developed. Compaction below the depth of normal tillage operation is generally called subsoil compaction. These hinder root penetration, water and nutrient uptake by crops. Such a pan is about 4-5 cm thick and is widespread in paddy soils of Pakistan (Rafiq, 1990). However, enough data are not available about the degree of severity of the problem or the area affected.

Soil crusting and sealing of the surface for a few millimetres reduce seedling emergence and penetration of water into soils. Crusts and seals are similar, except crusts develop when soils dry while seals occur when soils are wet. Soils of Pakistan have low organic matter, high silt and /or ESP, and thus more susceptible to surface crusting. It is a serious problem in 4.7 mha of clayey soils under irrigation and moderate to minor problem in 2.3 mha of dry-farmed land (Rafiq, 1990).

A little research work has been done in Pakistan regarding the application of soil physics for improving degraded soils, mainly due to lack of trained manpower and research facilities in the soil physics. Now the World Bank has funded projects to facilitate necessary research and training. Findings pertaining to physical soil degradation are presented in these sections.

Improving crop growth in crusting soils. Sowing methods can help to get better plant stand and thus improved crop yield on surface sealing or crusting soils. Chaudhry and Rafique (1984) reported that 'flat' sowing of cotton increased crusting and gave lower yield mainly due to poor aeration, while sowing on single or double row beds gave higher yield. Similarly, Qureshi and Aslam (1988) observed that sowing of wheat on 30 cm (2 lines), 45 cm (3 lines) or 60 cm (4 lines, 15 cm apart) wide beds significantly increased grain yield compared to normal flat sowing on a salt-affected loamy clay soil. Furrow irrigation supplied sufficient water for growth through lateral seepage and reduced crusting, resulting in good aeration.

Soil crusting is an important problem in rainfed agriculture. It reduced seed germination and water infiltration, and increased run off which result in nutrient and soil losses (Nizami & Khan, 1989). Under rainfed conditions at three different locations, soil crust strength was the greatest in soils having higher proportion of clay, fine silt or fine sand in the surface. The plant population and the grain yield of maize within a soil family decreased as the intensity of soil crust increased. It was noted that the effect of crust on a soil family was the same at three locations. However, in another study, Nizami and Khan (1991) observed that decrease in yield and plant population by the intensity of soil crust differed among sites.

Under rainfed conditions in the Pothowar area (Nizami *et al*., 1995; Nizami & Salim, 1997), studies were conducted to evaluate the effect of crusting on crops. In first study, four soil series were investigated. Then six soil series (including these four) namely Guliana (SiCL), Khaur (SiCL), Missa (SiL), Pir Sabak (SiL), Balkassar (SL) and Khair (SL) were selected for the second study. The soil treatments were: Fertilizer without hoeing (A), farmyard manure with no hoeing (B), fertilizer + grass mulching without hoeing (C) and fertilizer with hoeing (D). The applied nutrient status of all the treatments was kept uniform. Soil crust intensity decreased from 6.3 to 1.5 kg cm^{-2} as the texture changed from SiCL to SL, while increased with an increase in silt and clay contents and was inversely proportional to organic matter and soil water contents. With an increase in soil crust intensity, the plant population decreased. It was concluded that soil structure and aggregate stability can be improved by using organic manures. The highest increase (81- 144%) in grain yield was noted with hoeing on the Guliana, Khaur and Missa soil series (Table I). On the Pir Sabak soil, mulching and hoeing showed similar response, and treatment C was the most effective on the Balkassar and Khair (SL) soils. An economic analysis showed that hoeing was the best treatment for managing crust in the Khaur, Guliana and Missa soils; mulching and hoeing were equally good for Pir Sabak soil and mulching was the best for Balkassar and Khair (SL) soil series, i.e. site-specific response to treatments.

Shafiq *et al.* (1994a) concluded and recommended that occasional tillage operations be carried-out during summer season to break crust and eradicate weeds, which will increase water conservation. Micrographs of sequential exposures of soil crust were taken perpendicular to the surface. Visual observations suggested that the soil crust taken from conventional and deep tilled plots had fewer and smaller voids than zero tilled plots. The pores were open to the soil surface and their edges were sharp in samples from zero tilled plots.

Soil compaction. Sheikh (1976) found a linear decrease in seed germination with increasing soil BD. In a laboratory study (Sabir *et al*., 1990), wheat germination was maximum at 1.2 Mg m^{-3} BD and minimum at soil BD of 1.4 Mg m^{-3}. The germination was maximum (82%) at 2.5 cm sowing depth with 1.2 Mg cm^{-3} BD and 16% soil water content. The lowest seedling emergence (17%) was recorded at 5 cm deep seed placement at 1.4 Mg m^{-3} BD and 12% water content. It was concluded that the tillage implements be selected to produce a BD of 1.2 Mg m^{-3} at 16% soil water content at the sowing depth of 2.5 cm to improve wheat seedling emergence.

In a field experiment (Adhikari, 1989), wheat was grown in wheel-compacted and chiselled plots with or without FYM. Soil strength and BD increased while the saturated hydraulic conductivity (K_s) decreased with increasing compaction but statistically remained similar to that of the control. Grain yields were significantly decreased by compaction while chiselling produced higher yields, possibly due to improved physical properties, particularly K_s of soil.

Compaction characteristics of a clay loam soil were studied under laboratory and field conditions (Shafiq *et al*., 1994b). The laboratory study over-predicted the compaction compared with the field conditions. Soil water content had a more effect than load on soil BD or compaction. The penetration resistance varied with water content, whereas K_s decreased with an increase in BD. The compaction effects were more pronounced in the surface 0.0-0.1 m, but were negligible at 0.1-0.2 m depth when tillage machinery was used at higher soil water contents or when similar conditions were simulated in the laboratory.

Table I. Effect of various soil crust management practices on grain yield (kg ha^{-1}) of maize

Soil Series	Control (T_1)	FYM (T_2)	Mulching (T_3)	Hoeing (T_4)
Guliana	2280	4165 (82.7)	4815 (111.2)	5570 (144.3)
Khaur	1365	2858 (109.3)	3347 (145.1)	3722 (172.6)
Missa	2356	3690 (56.6)	3918 (66.3)	4267 (81.1)
Pir Sabak	3013	3844 (27.6)	4513 (49.8)	4410 (46.4)
Balkassar	2546	2910 (14.3)	3521 (26.5)	2813 (10.5)
Khair (SL)	2885	3263 (13.1)	3615 (25.3)	3245 (12.4)

Figures given within brackets is the per cent increase in grain yield by soil crusting amendment

Thus, fields must be properly terraced and levelled to have low spatial variability in surface soil water contents at the time of tillage to minimize the compaction. The compaction effects at surface (0.1 m) can be minimized through appropriate tillage operations and it can be avoided at 0.1-0.2 m depth if tillage is performed up to 40% of available water.

Aslam *et al*. (1998) observed that growth of *Eucalyptus camaldulensis* was poor on more compact and hard soils since compacted soils had negative effect on infiltration rate of soils, nutrient availability and root penetration, the result has to be poor growth. Tree based strategies could be helpful in the improvement of soil permeability due to more development of roots and enhanced root exudates in salt-affected and compacted soils.

Table II. Effect of sub-surface compaction on wheat yields and nutrient uptake (kg ha^{-1})

Treatment	Grain	Straw	P-uptake	K-uptake
No-compaction	3719 a	6050 a	17 a	126 a
Compaction	2259 b	5541 b	10 b	98 b

Ishaq *et al*. (2000a) studied the effect of sub-surface (at 0.15 m depth) soil compaction on grain and straw yields, and nutrient uptake of wheat. He noted a significant decrease in both grain and straw yields in compacted (BD = 1.93 Mg m^{-3}) than that of non-compacted (BD = 1.53 Mg m^{-3}) soils (Table II). In another study, Ishaq *et al*. (2000b) reported that increase in soil strength due to subsoil compaction decreased the nutrient uptake by wheat and sorghum and root length density of wheat. The reduction in nutrient uptake by wheat due to compaction was 12-35% for N, 17-27% for P and up to 24% for K. The reduction in nutrient uptake in sorghum due to subsoil compaction was 23% for N, 16% for P and 12% for K. Root length density of wheat below 0.15 m depth was significantly reduced and was significantly correlated with soil bulk density.

Soil under wheat-rice had a layer of high BD of 1.71 Mg m^{-3} at 10-20 cm depth and lower K_s of 3.8 cm day^{-1} compared to the BD of 1.52 Mg m^{-3} and K_s of 9.14 cm day^{-1} under wheat-maize system (Hassan & Gregory, 1999). Puddling reduced the volume of pores > 3.0 μm and increase the volume of pores having <0.3 μm diameter in the wheat-rice system.

Tillage for improving crop growth and physical conditions of degraded soils. Tillage operations generally improve soil permeability and allow increased root proliferation, which might improve the supply and utilization of nutrients to plants, particularly in soils with hard pans. In a field experiment Ghafoor *et al*. (1985 a & b) carried-out subsoiling (50 ± 5 cm deep, 120-150 cm apart crosswise furrows) to shatter the high $CaCO_3$ compact layer in the sub-soil. Gypsum @100% soil GR was applied with or without subsoiling to reclaim the Khurrianwala (SCL to CL) and Gandhara (SiL to SiCL) soil series using brackish tube well water. Subsoiling alone restored grain yield of wheat within two years on the Khurrianwala soil series, while that of paddy remained equal or superior to other treatments. However, sub-soiling alone failed to improve wheat or rice yields compared with other treatments in the adjoining fine-textured Gandhara soil series where the main problem was more silt. Silt size particles can clog the pores, resulting in reduced soil permeability. So the effect of subsoiling could persist for a short time under relatively fine-textured soil conditions, especially having high silt contents. The soil-applied gypsum increased the crop productivity through better seedling emergence due to decreased soil crusting.

Continued shallow cultivation has been reported to create a hard pan below 0.15 m depth, which restricts infiltration to lower depth (Razzaq *et al*., 1990). Therefore, about 50% of annual rainfall was lost as surface run off. Khan *et al*. (1980) found that contour terracing and deep tillage in such soils increased infiltration of rainfall and provided water for plant uptake and thus increased 2-3 fold the yield of wheat, maize, sorghum, groundnut and soybean.

Campbell *et al*. (1988) compared normal shallow tine cultivation to 15 cm soil depth and deep tillage with mouldboard plough to 30 cm soil depth for wheat at four locations. There was a positive wheat grain yield response in all the experimental plots. There was greater water utilization at 30 to 45 cm depths in the deep mouldboard tilled plots compared to shallow tine tilled plots during the period of low rainfall. Mouldboard tillage increased wheat yield due to two reasons, i.e. on one hand soil strength decreased which allowed greater and deeper root development, and thus increased evapotranspiration (ET) and on the other hand during heavy rainfall, deep tillage enabled greater soil water recharge which, in turn, increased ET without depleting soil water storage for long time.

In a sandy loam soil, Majid *et al*. (1987) observed maximum number of grains per spike (66.5) with chisel ploughing while maximum wheat grain yield (5.5 Mg ha^{-1}) was noted for the mouldboard plough plus rotavator with 28% increase over conventional tillage. Similarly, Shafiq *et al*. (1987) on a silt loam soil recorded the highest grain yield with deep ploughing attributable to the combined effect of decreased BD and increased soil water contents. In a field experiment from 1989-90 to 1990-91, Shafiq *et al*. (1994c) compared no-till, conventional tillage (narrow tine cultivation to 0.15 m depth) and deep tillage (mouldboard ploughing to 0.25 m depth). There was no

Table III. Effect of fertilizer rates and tillage on wheat grain yield (kg ha^{-1})

Fertilizer (kg ha^{-1})	Tillage operation Minimum	Conventional	Chisel	Mouldboard	Mean
a. Year 1996-97					
60-45-30	2168	2890	2499		2519 B
120-90-60	2796	3883	3142	-	3274 A
180-135-90	3821	3576	3559	-	3652 A
Mean	2928 B	3449 A	3066 B	-	-
b. Year 1997-98					
60-45-30	3368	3296	3371	4455	3622 B
120-90-60	3982	4721	4103	4906	4428 A
180-135-90	4799	4558	4688	4753	4699 A
Mean	4049 B	4192 B	4054 B	4705 A	-

effect of tillage treatments on grain yield of wheat during 1989-90. During 1990-91, the lowest grain yield of 1.94 Mg ha^{-1} was noted for zero tillage under wheat-fallow-wheat and the highest (2.98 Mg ha^{-1}) for deep tillage under the same cropping system. This response in grain yield is attributable to weed biomass difference because increase in yield due to weed control was 35, 12 and 10% for zero, conventional and deep tillage treatments, respectively.

Ishaq (2000a) studied the effect of different fertilizer rates and tillage practices on yield of wheat and seed cotton in a long-term experiment under field conditions. He observed that grain yield of wheat was significantly higher in case of conventional tillage compared to chiselling and minimum tillage during the year 1996-97 (Table III). He included mouldboard tillage next year (1997-98) in the plan before sowing wheat and under this treatment, a significant increase in wheat yield was observed compared to other three tillage practices. However, chiselling increased the cotton yield significantly compared to conventional tillage during the year 1996 (Table IV).

Soil and water conservation. The Pothowar plateau is a large rainfed tract comprising 1.82 m ha, out of which 0.61 m ha are cultivated and remaining is affected by gully erosion. Ahmad *et al*. (1990) developed relationship between run off and soil loss from the cultivated fields at Fateh Jang watershed in Pothowar area. They studied the effect of surface cover and gradient on run off and soil loss in an integrated land use system. These experiments were conducted in an area having annual rainfall of 750 mm. The contour bunding was done in area cropped with traditional practices, contour terracing was done in gully beds and on the sides, contour bunding without land shaping was done for pasture area while eye-brow terracing, reverse slope terracing and conservation catchment terracing for tree plantation area. Land with slope > 10%, shallow soils with low water holding capacity and undulating topography was developed as plantation area. The surface cover reduced the annual run off by 10-18% during 1983 to 1988 due to which soil loss was reduced by 50%. The variation in topography, soil depth and cost of various land forming techniques indicates a need to have an integrated approach to make decisions on land forming and land use.

Table IV. Effect of fertilizer rates and tillage practices on yield of seed cotton (kg ha^{-1})

Fertilizer (kg ha^{-1})	Tillage operation			
	Minimum	Conventional	Chisel	Mean
85-42-30	2384	2146	2613	2381 B
170-85-60	2767	2375	2744	2629 A
225-127-90	2502	2657	2862	2774 A
Mean	2551 AB	2392 B	2740 A	

In a long-term field study, it was observed that BD significantly decreased while organic matter contents and nitrate-N increased (Shafiq *et al*., 1994d). Cumulative infiltration after three hours was 107 and 67% greater under catchment planted with *Leucaena leucocephala* and *Eucalyptus camaldulensis* than control catchment, respectively. No surface run off was observed in *Leucaena leucocephala* catchment and with *Eucalyptus camaldulensis,* it decreased by 21% as compared with that of the control.

CONCLUSIONS

- Sowing on beds rather than on normal flat beds improved wheat and cotton yields on crusting soils suggesting furrows irrigation better than flood irrigation.
- Management practices, like hoeing or grass mulching with or without organic matter and gypsum are necessary for crusting soils to improve aggregate stability.
- Deep ploughing with mouldboard plough proved beneficial for crops and soil physical condition, particularly for soils having sub-surface compaction.
- Soil water content has a more pronounced effect than load on soil compaction. Tillage operations should be avoided when water contents are > 40% of the available water.
- Surface cover reduced surface run off and improved soil and water conservation.
- Subsoil compaction decreased the nutrient uptake by wheat and sorghum and root length density of wheat.

REFERENCES

Adhikari, K.R., 1989. Effect of compaction on physical properties of soil and yield of wheat. M.Sc. (Hons.) Thesis, Department of Soil Science, Univ. of Agri., Faisalabad.

Ahmad, S., M. Khan and M.Z.U. Ikram, 1990. Soil and water conservation and integrated land use in Pothowar, Pakistan. *Proc. Int. Symp. on Applied Soil Physics in Stress Environments*. Jan. 22-26, 1989, Islamabad, Pakistan. pp: 301–12.

Aslam, M., M. Nasim, R.H. Qureshi, J. Akhtar and S. Nawaz, 1998. Effect of spatial variability of soil salinity and sodicity on the performance of *Eucalyptus camaldulensis. Proc. ICID Workshop on the Use of Saline and Brackish Water for Irrigation*. July 23-24, 1998, Bali, Indonesia.

Campbell, J.A., M.E. Akhtar, A. Khan and C.G. Hussain, 1988. Crop responses to tillage practices under dry land conditions of northern Pakistan. *Proc. Int. Seminar on Dry Land Agri. in Pakistan.* Nov. 6-8, 1988, Lahore, Pakistan. pp: 159–88.

Chaudhry, M. R. and M. S. Rafique, 1984. Stand establishment of cotton on salt-affected soils. *Mona Recl. Expt. Project Publ.*, 141, Mona Bhalwal, Pakistan.

Ghafoor, A., S. Muhammed and A. Rauf, 1985b. Field studies on the reclamation of Gandhara saline-sodic soil. *Pakistan J. Agri. Sci.,* 22: 154–63.

Ghafoor, A., S. Muhammed and N. Ahmad, 1985a. Reclamation of Khurrianwala saline-sodic soil. *Bull. Irrigation Drainage and Flood Control Res. Council,* 15: 23–8.

Hassan, M.M. and P.J. Grgory, 1999. Water transmission properties as affected by cropping and tillage systems. *Pakistan J. Sci.*, 16: 29–38.

Ishaq, M., A. Hassan, M. Saeed, M. Ibrahim and R. Lal, 2000a. Subsoil compaction effects on crops in Punjab, Pakistan: I. Soil physical properties and crop yield. *Soil Till. Res.,* (Submitted).

Ishaq, M., M. Ibrahim, A. Hassan, M. Saeed and R. Lal, 2000b. Subsoil compaction effects on crops in Punjab, Pakistan: II. Root growth and nutrient uptake. *Soil Till. Res.,* (Submitted).

Khan, B. M., S. Ahmad and I. Ashraf, 1980. Rain moisture conservation for crop production in Pothowar area of Pakistan. *Soil and Water Res. Report* 1. Dir. S&I, PARC, Islamabad.

Majid, A., M. Afzal and I. Ahmad, 1987. Effect of different tillage techniques on wheat production after rice. *Pakistan J. Agri. Res.,* 8: 199–203.

Nizami, M.M.I. and M. Salim, 1997. Studies on crop stand and grain yield of maize as influenced by soil crusting in different soil series. *Pakistan J. Soil Sci.*, 13: 62–5.

Nizami, M.M.I. and N.A. Khan, 1989. The effect of soil crust on yield of maize crop on three soil families under rainfed conditions. *Pakistan J. Soil Sci.*, 4: 25–9.

Nizami, M.M.I. and N.A. Khan, 1991. Soil crust effects on plant population and grain yield of maize. *Pakistan J. Agri. Res.,* 12: 40–5.

Nizami, M.M.I., M. Salim and M.S. Zia, 1995. Management of soil crust in Pothowar area under rainfed conditions. *Pakistan J. Soil Sci.*, 10: 6–9.

Qureshi, R.H. and M. Aslam, 1988. Research on utilization of degraded lands, Sadhoke. First Annual Report 1987-88. Dept. Soil Sci., Univ. Agri., Faisalabad, Pakistan. pp: 8–10.

Rafiq, M., 1990. Soil resources and soil related problems in Pakistan. *Proc. Int. Symp. on Applied Soil Physics in Stress Environment.* Jan. 22-26, 1989, Islamabad, Pakistan, pp: 16–23.

Razzaq, A., N.I. Hashmi and A. Majid, 1990. Results from on-farm agronomic research in Fateh Jang, FSR project area from 1987 to 1990. Coordinated wheat, barley and triticale programme. NARC, Islamabad, pp: 1–23.

Sabir, M.S., M. Ahmad and M. Aslam, 1990. Investigation of tillage requirement for wheat seedling emergence. *Pakistan J. Agri. Sci.*, 27: 34–8.

Shafiq, M., A. Hassan and S. Ahmad, 1994b. Soil physical properties as influenced by induced compaction under laboratory and field conditions. *Soil and Tillage Res*., 29: 13–22.

Shafiq, M., A. Hassan, N. Ahmad and A. Rashid, 1994c. Crop yields and nutrient uptake by rainfed wheat and mungbean as affected by tillage, fertilization and weeding. *J. Plant Nutr.*, 17: 561–77.

Shafiq, M., A. Hassan, S. Ahmad and M.S. Akhtar, 1994a. Water intake as influenced by induced compaction and tillage in rainfed areas of Punjab (Pak.). *J. Soil and Water Conserv.,* 49: 302–5.

Shafiq, M., M.Z. Ikram, M. Ahmad and M. Aslam, 1994d. Soil characteristics and surface run off as affected by vegetative cover under rainfed conditions. *J. Engg. and Appl. Sci.*, 13: 25–8.

Shafiq, M., R. Amin and M. I. Nizami, 1987. Crop yields as affected by different tillage treatments under rainfed conditions of Pothowar. *Pakistan J. Soil Sci.*, 2: 1–5.

Sheikh, G.S., 1976. Soil resistance and emergence of seedling. *Pakistan. J. Agri. Sci.*, 13: 41–8.

(Received 12 May 2000: Accepted 25 June 2000)