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Soil Management for Enhancing Nutrient Availability in Some Physically Constrained Soils

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ABSTRACT

Increasing nutrient use efficiency is important for meeting the nutrient requirements of crops under reduced fertilizer supplies. A number of physical constraints limit nutrient utilization and yields of crops in different agro-ecological regions of the country. Certain soil management practices could moderate the soil physical environment and enhance root growth and nutrient uptake. The practices hold more promise for rainfed areas with low fertilizer use. More studies should be taken up on tillage x nutrient interactions to effect savings in fertilizer use.

Key words: Soil physical constraints, Nutrient use efficiency, Soil management practices.

Introduction

India has to produce 310M tonnes of food grains by 2050 to feed the projected population of about 1.5 billion. There would be a requirement of 20.2, 27.3 and 31.3 M tonnes of N, P and K by 2011, 2031 and 2051, respectively to meet the nutrient needs of crops. The fertilizer production during the corresponding periods is, however, expected to be 15.8, 20.9 and 23.9 M tonnes, registering a gap of 4.4, 6.4 and 7.2 M tonnes, respectively (Table 1). The very pertinent question arises as to how to achieve the required food production targets in the face of short supplies of nutrients. Enhancing nutrient use efficiency, which is dismally low for majority of the nutrients (Table 2), could be one of the options. A number of soil physical constraints like poor hydro-thermal regimes, mechanical impedance, crusting, high permeability, soil erosion, limited soil depth, poor drainage, salinization and alkalization etc result into unfavourable soil environment for nutrient availability and utilization by crops.

Russell (1975) expressed that yields were limited by the physical conditions of the soils rather than their nutrient status in certain situations. Hillel (1980) further stated that suitability of soil as a medium of plant growth depends on both its chemical and physical fertility. While chemical fertility refers to nutrient status, soil reaction and freedom from toxic elements; the physical fertility describes state of soil in respect of flow of water and air, thermal regimes and mechanical resistance to growing seedlings and roots. The adverse physical soil environment limits root growth and its activity and results in reduced nutrient absorption and growth of plants (Drew, 1978; Chaudhary and

Table 1. Projections on demand and availability of fertilizer nutrients (N P K in mt)

Year	Demand	Availability	Deficit
2011	20.2	15.8	4.4
2031	27.3	20.9	6.4
2051	31.3	23.9	7.2

Table 2. Use efficiency of Nutrients

Nutrient	Use efficiency (%)
N	30-50
P	10-20
K	<80
S	8-12
Zn	2-5
Fe	1-2
Cu	1-2
Mn	1-2

Source: Takkar *et al.* (1997)

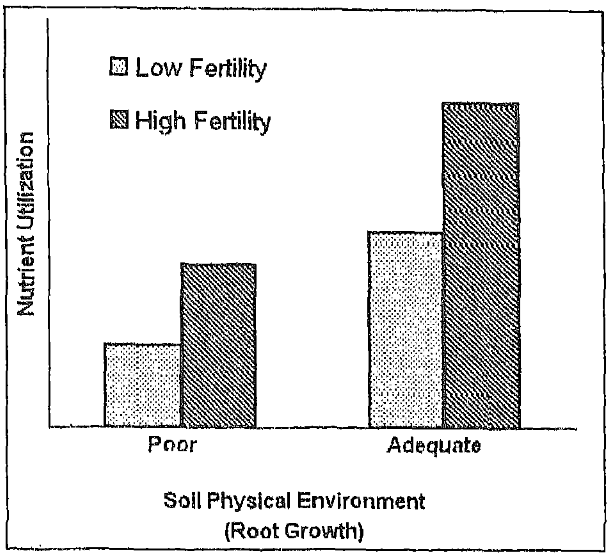


Fig. 1. Relationship between root growth and nutrients utilization (schematic)

Sandhu, 1983 and Peterson *et al.*, 1984). The nutrient utilization could be poor with reduced root growth even under high fertility situations (Fig. 1). The better physical environment, conversely, induces more proliferation of roots laterally and vertically into deeper layers ensuring more utilization of mobile and immobile nutrients.

The soil physical constraints, limiting nutrient utilization and crop production, could be alleviated by adopting certain soil management practices that moderate soil environment. The adoption of such practices may be of more value for dry land areas facing frequent moisture stress and having low fertilizer use (Table 3). This paper is mainly based on the experiences gained in an All India Co-ordinated Research Project on Soil Physical Constraints and their Amelioration for Sustainable Crop Production of ICAR.

Mulching

The practice of covering soils with waste organic residues greatly aids in moderating soil hydro-thermal regimes and enhancing nutrient availability. The productivity of crops in north-west Himalayan region is low due to frequent moisture stress, sub-optimal temperatures during winter months and low nutrient use efficiency. The application of pine needle mulch @10 t/ha both to tilled (CT+M) and non-tilled (NT+M) soils increased moisture availability, minimum temperature during winter months, root growth and nutrient utilization by crops compared to conventional tilled (CT) and non-tilled (NT) soils (Bhagat and Acharya, 1987; Sharma and Acharya, 1987). The uptake of N by maize grain under CT+M was significantly more by 22.3, 40.4 and 53.3 % compared to CT in 1983, 1984 and 1985, respectively (Table 4). Likewise, the uptake of P by the wheat grain was significantly higher by 53.3, 48 and 82.3 % during these three consecutive crop seasons, respectively (Table 5). The NT+M also resulted in a general increase in the nutrient uptake by grain of both maize and wheat compared to NT. For instance, the significant increases in K uptake by wheat grain for the three consecutive crop seasons were 59, 69.3 and 84.7 %, respectively (Table 6). The greater uptake of nutrients with mulches over tilled and untilled plots was due to better root growth conditioned by better moisture supply, favourable soil temperatures and less impedance to root proliferation. The fibrous and more active root system under mulches would offer more nutrient absorption sites per unit root mass. Also, the greater spread of roots through a larger volume of soil would aid greater removal of relatively immobile nutrients like P and K (Weill *et al.*, 1990). There are other studies too to suggest that the presence of organic residues on the surface induced more root growth and resulted in increased removal of nutrients by crops (Singh *et al.*, 1966; Triplett and Van Doren, 1969; Moschler *et al.*, 1972; Moschler and Martens, 1975; Power *et al.*, 1986; Thiagalingam *et al.*, 1991).

Table 3. Fertilizer consumption under rainfed conditions

Size of holding	Consumption of fertilizer (Kg/ha)
Marginal (< 1.0 ha)	40.1
Small (1.00-1.99 ha)	36.5
Semi Medium (2.00-3.99 ha)	31.6
Medium (4.00-9.99 ha)	27.7
Large (>10.00 ha)	17.0
All Categories	30.5

Source: Fertilizer Statistics. 2002-03, FAI

Table 4. N uptake by grain (kg ha^{-1}) in maize and wheat under different management practices on an Alfisol, Palampur

Treatment	1983-84		1984-85		1985-86	
	Maize	Wheat	Maize	Wheat	Maize	Wheat
CT	56.lb	32.9b	40.6b	34.7a	44.3b	31.6b
CT+M	68.6a	53.4a	57.0a	41.1a	67.9a	42.2a
NT	44.1c	33.9b	26.7c	28.1a	17.7a	29.lb
NT+M	56.9b	44.6ab	38.4bc	40.1a	62.8a	45.3a

Source: Acharya & Sharma (1994)

Table 5. P uptake by grain (kg ha^{-1}) in maize and wheat under different management practices on an Alfisol, Palampur

Treatment	1983-84		1984-85		1985-86	
	Maize	Wheat	Maize	Wheat	Maize	Wheat
CT	12.4bc	4.5b	8.4ab	2.5b	9.4b	1.7a
CT+M	17.4a	6.9a	11.3a	3.7a	16.5a	3.Iab
NT	11.8bc	4.2c	6.2b	2.4b	3.0a	2.5bc
NT+M	11.0c	5.3b	11.8a	3.3a	10.0b	3.8a

Source: Acharya & Sharma (1994)

Table 6. K uptake by grain (kg ha-l) in maize and wheat under different management practices on an Alfisol, Palampur

Treatment	1983-84		1984-85		1985-86	
	Maize	Wheat	Maize	Wheat	Maize	Wheat
CT	21.9ab	7.lbc	18.8b	9.8ab	26.5a	8.7bc
CT+M	28.4a	9.1a	37.1a	13.7a	30.8a	12.0a
NT	16.4b	5.6c	13.7c	7.5b	8.5b	7.2a
NT+M	16.6b	8.9a	26.7a	12.7a	27.2a	13.3a

Source: Acharya & Sharma (1994)

Deep Tillage/ Sub Soil Chiseling:

The presence of sub-soil hard pan impedes movement of water and air in the soil, restricts root growth and reduces uptake of nutrients. The contribution of sub-soil fertility to crop growth is meagre under these situations. The hard pan may develop due to illuviation of clay to sub-soil horizon coupled with cementing action of oxides of iron and aluminium and calcium carbonate as evident in red soils. It may also develop, especially in irrigated situations, by continuous cultivation of soils with heavy machinery without varying the depth of cultivation. About 11.3 M ha of cultivable land is affected by such constraints. The studies at various locations suggest that breaking/shattering of the compact layers improves the nutrient availability and yields of crops. The management practice to be followed depends on the depth of occurrence of hard pan.

The chiseling of soil at Coimbatore (falling under semiarid ecosystem and belonging to Pichanur series, Alfisol) having hard pan at a depth of 15 cm, significantly enhanced the grain yield of rainfed sorghum as compared to other tillage systems cultivating soil to relatively lesser depth (Table 7). The interaction of tillage and nitrogen revealed that higher yield could be obtained with chiseling even at lower doses of nitrogen. For instance, the yield obtained at 135 kg N/ha with cultivator could be achieved by applying only 90 kg N/ha with the practice of chiseling. The efficient N-use under chiseling could be attributed to improved soil physical environment evident in low bulk density and higher hydraulic conductivity values (Painuli, 2000). The beneficial effect of chiseling could be seen even on the succeeding crop. The yields of black gram obtained at highest dose of N with cultivator could be realized without application of N under chiseling (Table 8). Thus, there could be large saving of fertilizer N for rainfed sorghum-black gram cropping system by following practice of chiseling.

Table 7. Interaction of tillage and N on grain yield of sorghum (q ha^{-1}) on an Alfisol with an impeding soil layer (Coimbatore)

Tillage	Nitrogen level (Kg/ha)				
	0	45	90	135	Mean
Cultivator once	941	1158	1487	1378	1241
Cultivator twice	878	1045	1285	1400	1152
Chisel plough + disc plough	1148	1248	1345	1748	1372
+ cultivator twice	989	1150	1372	1509	
	T	N	T on N	N on T	
CD at 5%	168	86	154	158	

Source: Painuli (2000)

The nutrient use efficiency and crop yields could also be improved on slowly permeable Vertisols of Coimbatore (Perianaicken palayam series) with deep/intensive tillage. These soils with high swelling type clay content (>40 %) have, generally, low infiltration rates of < 6 cm/day. The water stagnating in these soils reduces oxygen availability and, thereby, the availability and uptake of nutrients. The deep/intensive tillage helped economize on N while causing no reduction in yield. The yields of maize with Disc plough once + cultivation twice +135 kg N/ha were comparable with cultivation once + 200 kg N/ha (Table 9).

Table 8. Interaction effect of residual tillage and nitrogen on grain yield of black gram (kg ha^{-1}) in an Alfisol with an impeding soil layer (Coimbatore).

Tillage	Nitrogen level (Kg/ha)				
	0	45	90	135	Mean
Cultivator once	178	222	247	248	224
Cultivator twice	225	197	222	214	214
Chisel plough + disc plough + cultivator twice	312	345	347	412	354

Source: Painuli (2000)

Table 9. Effect of tillage and N on the grain yield of maize (kg ha^{-1}) in a slowly permeable Vertisol, Coimbatore

Tillage	Nitrogen (kg/ha)				
	0	67.5	135	200	Mean
Cultivator once	2198	2248	2478	2673	2399
Cultivator twice	2245	2758	2897	2898	2700
Disc plough once + cultivator twice	2448	2589	2879	3014	2732
Mean	2297	2532	2751	2862	2610

Source: Painuli (2000)

A compact layer in a Jobner sandy loam soil belonging to Entisol also limits nutrient availability and crop yields. The simple chiseling of this layer (without any N) resulted in realizing the same yields of pearl millet as were obtained with the application of 60 kg N/ha with farmer's practice (Table 10). The breaking of hard pan had resulted in lower bulk density, increased hydraulic conductivity, more infiltration rate and better profile moisture (Painuli, 2000).

The intensive farm operations have resulted in the formation of dense soil layers at shallow depths

Table 10. Interaction of tillage and nitrogen on grain yield (q ha^{-1}) of pearl millet on an Entisol with an impeding soil layer (Jobner)

Tillage	Nitrogen level (kg ha^{-1})					
	Kharif 1998			Kharif 1999		
	0	30	60	0	30	60
Farmer's practice	10.66	12.38	12.95	8.16	9.40	10.55
Disc harrow (20 cm)	12.43	13.15	13.71	10.20	11.65	12.24
Disc plough (30 cm)	13.05	13.77	14.34	11.40	12.21	12.95
Chiseling (45 cm)	14.33	15.05	15.62	12.84	13.55	14.02
CD at 5 %		0.798			1.892	

Source: Painulli (2000)

(Plough sole) in sandy loam soils of Haryana (Arid ecosystem). The breaking of such layers enhanced N and P use efficiencies and yields of raya (Table 11). The deep tillage saved about 25 % of fertilizers.

Table 11. Interactive effect of tillage and fertilizer on yield (kg ha^{-1}) of *raya* in a sandy loam soil, Haryana

Tillage	Yield	
	Recomm-N and P	25 % more of recommended N and P
Conventional	814	949
Deep ploughing with disk plough	961	1080

Source: Painuli (2000)

The alluvial sandy soils developed under hyperthermic regime in semi-arid sub-tropical region of Punjab are characterized by unstable structure and a sharp increase in soil strength on their drying. A number of studies (Arora *et al.*, 1991, 1993; Gajari *et al.*, 1997) have established the benefits of deep tillage (sub soiling) on N-use, growth and yields of crops. Arora *et al.* (1991) reported better corn root growth with deep tillage (30 cm) in alluvial sand soil which alleviated nutrient stress by extracting and intercepting nutrients from the deeper layers. The corn yield with deep tillage + 80 kg N/ha was equal to yields obtained with shallow tillage + 240 kg N/ha (Table 12). The deep tillage, therefore, effected substantial saving of fertilizer nitrogen.

Table 12. Interaction of tillage and nitrogen on grain yield (t ha^{-1}) of winter corn in a deep alluvial sand soil, Ludhiana

Tillage depth (cm)	Nitrogen level (Kg/ha)			
	80	160	240	Mean
10	1.8	2.8	3.6	2.7
20	2.5	3.6	4.4	3.5
30	4.0	4.7	5.1	4.6
Mean	2.8	3.7	4.4	3.6

Source: Arora *et al.* (1991)

Similarly, deep tillage with chisel plough upto 30-35 cm resulted in better N utilization and grain yields of castor on a red sandy loam soil at Hyderabad (Singa Rao *et al.*, 1995). There was marked improvement in the active root distribution, studied with 32P soil injection technique, at 30 cm soil depth with deep tillage.

Soil Compaction

Generally, the soils with sand fraction more than 70 % exhibit high permeability (Infiltration rate > 20 cm /day). These soils unable to retain water and nutrients suffer nutrient loss with percolating waters. It is estimated that 13.75 M ha of lands in the country are affected due to this constraint. The compaction of these soils to a desired degree enhances their water and nutrient retention capacity by reducing percolation rates and hydraulic conductivity. The addition of clay adds to the efficacy of compaction if the soils are low in finer fraction (Painuli and Yadav, 1999).

The compaction of a loamy sand soil (belonging to Entisol) at Jobner with 8 passes of 500 kg iron roller and 4 passes of the same roller after mixing clay @ 2 % increased bulk density, decreased hydraulic conductivity, increased moisture content and decreased infiltrability of soils compared to farmer's practice (Tables 13, 14). It was possible to cut down N requirement from 80 kg/ha (farmer' practice) to 60 kg/ha with 8 passes of roller and to 40 kg/ha with 4 passes of roller after mixing clay with no reduction in yield of pearl millet (Table 15). The compaction, thus, effected 50 % saving in nitrogen compared to farmer's practice .The practice had sufficient residual effect on succeeding crop of wheat saving about 20-25 % N (Table 16).

Table 13. Effect of tillage practices on bulk density (Mg m^{-3}), saturated hydraulic conductivity (cm h^{-1}) and profile moisture content (cm m^{-1}) at sowing and harvest times of pearl millet on a loamy sand soil (Jobner)

Tillage	Depth (cm)	At sowing			At harvest		
		BD	HC	MC	BD	HC	MC
Farmer's practice	0-15	1.50*	10.87	10.48	1.49	10.33	5.21
	15-30	1.52	9.25		1.51	9.68	
	30-45	1.51	9.66		1.50	9.94	
8 passes of 500 kg iron roller	0-15	1.55	7.80	12.96	1.52	7.74	6.44
	15-30	1.60	6.10		1.57	6.34	
	30-45	1.57	6.70		1.54	6.75	
4 passes of 500 kg iron roller after mixing 2 % clay	0-15	1.55	6.18	14.31	1.53	6.97	7.16
	15-30	1.61	5.88		1.59	6.06	
	30-45	1.60	6.02		1.58	6.25	

*Geometric mean over two years
Source: Painuli (2000)

Table 14. Effect of tillage practices on infiltration rate (cm h^{-1}) and cumulative infiltration (cm) after one month of sowing of pearl millet on a loamy sand soil (Jobner)

Tillage	Time (Minute)						
	5	10	20	30	60	90	120
Farmer's practice	72.6* (6.0)#	62.6 (11.3)	57.6 (20.9)	50.8 (29.4)	39.0 (49.0)	33.4 (65.7)	28.6 (80.2)
8 passes of 500 kg iron roller	52.8 (4.4)	28.6 (7.9)	37.6 (14.2)	34.1 (19.6)	31.2 (35.2)	28.5 (49.5)	24.1 (61.6)
4 passes of 500 kg iron roller after mixing 2 % clay	40.2 (3.4)	36.3 (6.4)	33.2 (3.4)	30.6 (17.1)	25.6 (29.9)	21.6 (40.7)	17.4 (49.4)

*Geometric mean over two years
#Figures within parentheses indicate cumulative infiltration
Source: Painuli (2000)

Table 15. Interaction of tillage and nitrogen on grain yield (q ha^{-1}) of pearl millet on a loamy sand soil at Jobner

Tillage	Nitrogen level (kg/ha)				
	0	20	40	60	80
Farmer's practice	6.65	8.71	10.14	11.62	12.19
8 passes of 500 kg iron roller	8.36	10.92	11.80	12.77	14.06
4 passes of 500 kg iron roller after mixing 2% clay	9.12	11.81	13.74	15.25	16.84
CD at 5%	2.76				

Source: Majumdar *et al.* (1997)

Table 16. Interaction effect of residual tillage and nitrogen on grain yield (q ha^{-1}) of wheat on a loamy sand soil (Jobner)

Tillage	N (kg/ha)				
	0	60	90	120	150
Farmer's practice	16.68	25.04	29.61	34.82	36.42
8 passes of 500 kg iron roller	18.26	25.83	32.63	36.89	38.74
4 passes of 500 kg iron roller after mixing 2% clay	21.06	27.80	34.64	38.96	43.05

Source: Majumdar *et al.* (1998)

The paddy is grown on a fairly large area with high permeability. The compaction has been found effective in reducing nutrient loss through percolating waters. The increase in bulk density from 1.5 g/cm3 to 1.7 g/cm3 reduced infiltration rate and hydraulic conductivity by five times of a red sandy loam soil of Hyderabad (Table 17). The further increase in bulk density to 1.9 g/cm3, reduced the infiltration by eight times and hydraulic conductivity by thirty times of their original values. The compaction increased uptake of nutrients (N, P and K) and yield of paddy upto bulk density of 1.7 g/cm^3 (Table 18). The positive effect of compaction on nutrient use efficiency has also been reported by Ghildyal (1978). The increase in nutrient use efficiency by compaction could be attributed to reduced leaching losses as observed in a simulated column study (Table 19). The compaction beyond 1.7 g /cm^3 probably did not favour root growth and nutrient uptake. The compaction reducing leaching loss of NO_3-N by 75 % has been found to be desirable for sandy loam soils of West Bengal (Patil and Ghildyal, 1973). The compaction has also been found to be

Table 17. Effect of compaction on infiltration and hydraulic conductivity on a red sandy loam soil (Hyderabad)

Bulk density as a measure of compaction (g cm^{-3})	Equilibrium infiltration (cm h^{-1})	Hydraulic conductivity (cm h^{-1})
1.5	5.3	3.0
1.7	1.0	0.6
1.9	0.6	0.1

Source: Singa Rao *et al.* (1995)

Table 18. Effect of compaction on nutrient uptake and yield (harvest stage) of paddy on a red sandy loam soil, Hyderabad

Bulk density (g cm^{-3})	Nutrient uptake by grain (kg ha^{-1})			Paddy yield (q ha^{-1})
	Nitrogen	Phosphorus	Potassium	
1.5	48.0	11.8	9.4	46.9
1.7	50.2	12.9	11.4	47.8
1.9	36.6	11.6	9.0	29.4

Source: Singa Rao *et al.* (1995)

Table 19. Leaching losses of nutrients (kg ha^{-1}) in 6 weeks on a red sandy loam soil, Hyderabad

Treatments bulk density ($g\ cm^{-3}$)	N	P_2O_5	K_2O
1.5	29.5	12.6	28.0
1.7	17.7	8.9	14.9
1.9	8.9	4.8	6.2

Source: Singa Rao *et al.* (1995)

Table 20. Effect of "Drum Roller" compaction and nitrogen on grain yield of rice (kg ha^{-1}) in a fluffy rice soil at Coimbatore

Compaction by Drum Roller	Nitrogen level (kg ha^{-1})			
	0	50	100	Mean
Uncompacted	3365	3591	3917	3624
250 kg Compaction	3693	4167	4190	4017
400 kg Compaction	3838	4331	4510	4226
Mean	3632	4030	4206	

Source: Painuli (2000)

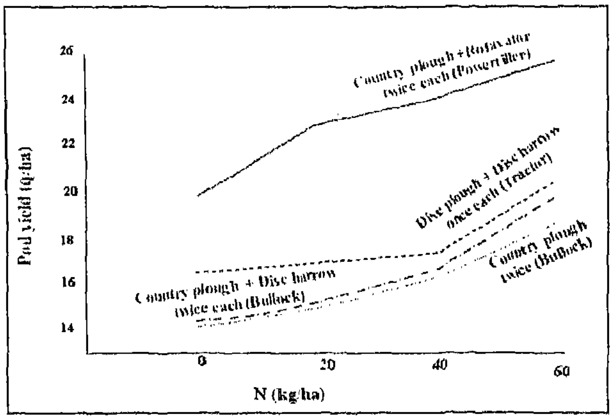
effective in saving 50 % N on fluffy rice soils (Table 20).

Soil Pulverization

The puddling for transplanted rice destroys soil aggregates and creates undesirable soil tilth for the following upland crop. Such a tilth would affect not only germination, but crop growth as well due to unfavourable soil physical environment. The constraint could be overcome by pulverizing soil with a rotavator. The rotavator created more proportion of finer aggregates with uniform size distribution. The rotavator tillage on a red sandy clay loam (chalka) soil in Andhra Pradesh increased N and P use efficiencies and pod yield of groundnut (Figs. 2, 3). The pod yield with rotavator tillage even without N equalled the yield obtained with country plough and 60 kg N/ha.

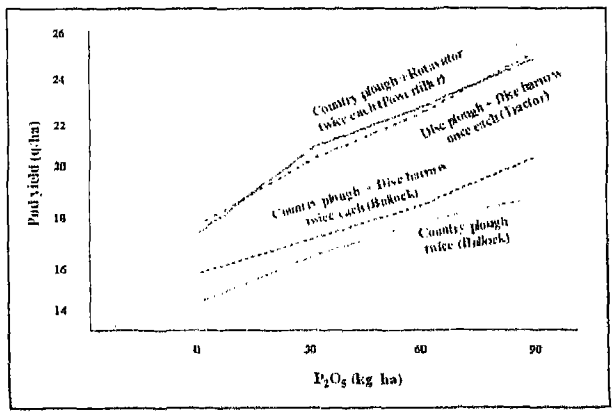
Conservation Tillage

Rice-wheat is an important cropping system occupying approximately 12 million ha in the Indo-Gangetic plain. There are reports of yield



Source: Singa Rao *et al.* (1995)

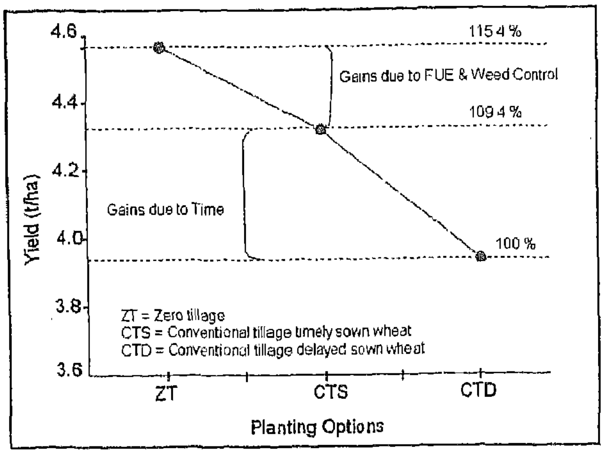
Fig. 2. Tillage and nitrogen interaction effect on yield of groundnut grown after puddled rice on a red sandy clay loam (chalka) soil of Andhra Pradesh



Source: Singa Rao *et al* (1995)

Fig. 3. Tillage and phosphorus interaction effect on groundnut yield after puddled rice on a red sandy clay loam (chalka) soil of Andhra Pradesh

stagnation of wheat after rice due to late planting, weed infestation and low fertilizer and water use efficiency. The zero tillage does away with these constraints and enhances wheat productivity (Hobbs *et al.*, 1997; Mehla *et al.*, 2000). In zero tillage, wheat is sown directly in the field immediately after the rice harvest, using a specially designed seed cum fertilizer drill. The zero tillage enhanced wheat productivity with timely sowing, reduced weed infestation and increased nutrient and water use efficiency (Fig. 4). Besides zero tillage, the laser levelling and bed and furrow resource conservation technologies (RCT's) also increase the nutrient use efficiency (Table 21).



Source: Mehla *et al.* (2000)

Fig. 4. Effect of tillage on fertilizer use efficiency and yield of wheat

Table 21. Resource conservation technologies and fertilizer use efficiency (% N P K)

Technology	Efficiency
Zero tillage	27.52
Laser leveling	26.91
Bed & furrow	24.32
Conventional	21.67

Source: Rice-wheat consortium paper series 14 (2002)

Conclusion

The future food demands under the decreased fertilizer supplies are to be met with the increase in nutrient use efficiency. A large number of soil physical constraints affect adversely the soil environment, nutrient utilization and crop yields. These constraints could be alleviated by adopting certain soil management practices. The adoption of practices may be more worthwhile in rainfed areas characterized by low fertilizer consumption and nutrient use efficiencies. The efficient nutrient use will reduce production costs by effecting savings on chemical fertilizer input and help mitigate fertilizer related pollution hazards. The high cost and unavailability of specialized tillage equipment come in the way of large scale adoption of soil management practices by the farmers. Our experience on tillage-nutrient interactions is still limited which requires to be focused to suggest tillage-specific fertilizer use.

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