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Improvement in physical properties of eroded agricultural soils through agronomic management practices

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ABSTRACT

Arable land in Pakistan is shrinking due to construction of houses and development of infrastructure, there has been a trend of shifting agriculture towards steep lands in order to feed the increasing population. Soil erosion on these lands is one of the most significant ecological restrictions to sustainable agriculture. A study was conducted during 2006-2008 to test the agronomic management practices for mitigating the adverse effects of soil erosion on arable soil. The experiment was designed in RCB with split plot arrangements. Cropping patterns, i e maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-maize (C1), maize-lentil (*Lens culinaris* Medic.)-maize (C2) and maize-wheat+lentil intercrop-maize (C3) were kept in main plots while fertilizer treatments; the control (T1), 50% NP also called farmers' practice (T2), 100% NPK or the recommended dose (T3) and 20 tonnes/ha farmyard manure integrated with 50% mineral N and 100% P and K (T4) were kept in sub-plots. Fertilizer treatments significantly improved soil physical properties in both depths. T4 showed the maximum improvement (13, 12, 22 and 31%) in bulk density, porosity, saturation and available water over the control and 3, 3, 8 and 7% over the T3 in surface soil. Cereal-legume rotation showed the maximum improvement while significant improvement in soil physical properties was noted with time, i e from *kharif* 2006 to *rabi* 2007. Highly significant negative correlation was observed between bulk density and saturation percentage (r^2=0.97) and bulk density and AWHC (r^2=0.93). It was concluded that NPK fertilizer alone cannot restore the physical environment of eroded soil to its maximum limit, but this objective could, rather, be achieved through mixed application of farmyard manure and mineral fertilizers. For this purpose, being an unstable nutrient element, recommended dose of mineral N must be reduced by 50% to avoid its over-application. In addition to other benefits of legumes in rotation, its improvement of physical properties further assert their importance in farming on such eroded lands.

Key words: Bulk density, Cropping patterns, Legumes, Organic and inorganic fertilizers, Physical properties, Soil erosion

World Bank report (2007) reaffirmed the role of agriculture in food security for the ever increasing population which, according to latest estimates, will reach 9 billion people by the year 2050 (UN 2008). As the linear expansion of land is not possible, in Pakistan rather it is shrinking due to construction of houses and development of infrastructure, there has been a trend of shifting agriculture towards steep lands. Soil erosion on these lands is one of the most significant ecological restrictions to sustainable agricultural production. The on-site effects are particularly important which includes loss of clay particles, plant nutrients, organic matter, degradation of soil structure, decreased rooting depth and decrease in available soil water, all of which have a negative effect on soil productivity (Khan *et al*. 2003, Khan *et al*. 2004).

Presently, concerns regarding soil conservation on cultivated sloping lands have led to the development of new strategies in order to maintain and protect soil physical properties. They are essential attributes on which the soil's productive capacity and its role as an environmental moderator depends (Acton and Padbury 1993). This needs appropriate restorative measures on degraded lands including recycling of the nutrient elements and to ensure optimum organic matter level required for crop production. In the face of regional energy crisis and increasing cost of fertilizers inputs, recycling of organic material is gaining importance. However, its availability is limited because of other competitive uses like fuel and fodder purposes. In most agriculture areas, harvests and livestock dung are brought to the houses and are used as energy or fodder sources. Under this situation integrated use of the fertility restorative measures including the use of legumes in crop rotation and application of both organic and inorganic sources of nutrients has emerged as a valuable strategy (Swarup 1998). Use of

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fertilizers from both organic and inorganic origin not only elevate the nutrient status of soil (Pratt 2008) but also bring about changes in physical, chemical and biological properties of the soil (Motavalli *et al*. 2003). Crop rotation with legumes helps restore and balance soil nutrient supply and is effective in boosting crop production from limited arable land (Yang 2006). Thus inclusion of legumes in continuous cereals and adequate P and K fertilization are the best integrated nutrient management for improving soil fertility and crop productivity (Sharma and Sharma 2004a). Cropping patterns that substitute chemically produced nitrogen either wholly or partly through biological nitrogen fixation (BNF) can help to reduce the use of costly chemical fertilizers. Biological nitrogen fixation is an important source of nitrogen input in many natural ecosystems. Thus in 1980s and onward, keen interest in crop rotation was observed due to concerns over impact of agriculture on the environment and the need to increase farm profit through diversification (Francis 1989). Better exploitation of BNF is one way to reduce the use of chemical nitrogen fertilizer in the future (Wartianien *et al.* 2008). Indeed, for obtaining valuable information, its study in the long-term soil fertility experiments is required to formulating future strategies for maintaining soil health.

While the present NPK fertilizer recommendations appear to maintain current average yield level, modification of the nutrient management including the application of nutrients other than mineral NPK fertilizers are likely to be required for degraded lands in order to sustain higher crop production (Mussgnug *et al*. 2006). This research work was focused to examine the potential of mineral fertilizers, farmyard manures, sole legume crop and legume-cereal intercrop in conserving and improving soil physical environment on eroded lands of District Swabi, Khyber Pakhtunkhwa, Pakistan.

MATERIALS AND METHODS

A field survey was conducted in District Swabi, Khyber Pakhtunkhwa province, Pakistan during May 2006 in coordination with Soil Survey of Pakistan, Field Office, Peshawar for the identification and selection of extensively cultivated eroded sites in farmers field. The site selected was classified according to the principles laid down in the key to soil taxonomy, USDA (1998).The site was identified as Pirsabak soil series with slight to moderate erosion hazard and USDA classification as fine, mixed, hyperthermic, Typic Haplustalfs.

Soil samples were collected from the selected site at two depths (0-20 cm and 20-40 cm) and were analyzed for the assessment of pre-sowing status of the physical properties and are given in Table 1.

Table 1 Physical properties of the composite soil samples before crop sowing

Soil parameters	Units	0-20 cm	20-40 cm
B. Density	Mg m^{-3}	1.43	1.46
Porosity	%	46	44.7
Saturation	%	26	25.8
AWHC	g kg^{-1}	126.4	123.3
Sand	%	14.5	12.2
Silt	%	59.4	59.8
Clay	%	26.1	28
Textural Class		Silt Loam	Silt Loam

Field experiments were conducted during 2006-2008 in randomaized complete block design (RCBD) with split plot arrangements. Three cropping patterns were tested in main plots; (i) maize (*Zea mays* L.)-wheat (*Triticum aestivum* L.)-maize (cereal-cereal rotation), (ii) maize-lentil (*Lens culinaris* Medic.)-maize (cereal-legume rotation, (iii) maize-lentil+wheat-maize (cereal-legume intercrop rotation) while the fertilizer treatments; the Control (T1), 50% NP also called farmer's practice (T2), recommended NPK dose (100% NPK-T3) and 20 tonnes/ha farmyard manure integrated with 50% N and 100% PK as mineral fertilizers (T4) were tested in sub-plots. Fertilizer treatments for cereal and legume crops has been given in Table 2.

Well decomposed farmyard manure at 20 tonnes/ha was applied on the site of experimentation about one month before sowing the crop. In case of farmersw' practice and the combined use of FYM and NPK, all the mineral fertilizers were applied at the time of sowing and incorporated into the soil. In case if recommended NPK dose, half N and all P and K were applied at the time of sowing and the remaining half N was applied one month after sowing to wheat and at knee high stage to maize crop. Maize variety Azam, wheat variety Uqab and lentil variety MN 92 were grown during the respective seasons.

Soil samples from each plot were collected after each crop harvest at two depths, i.e. 0-20 cm and 20-40 cm. Both core and disturbed samples were collected from all the sites in order to determine the following physical properties.

Soil texture was determined according to the procedure described by Tagar and Bhatti (1996). Soil bulk density was determined by core method as described by Blake and Hartge (1984). Total porosity (%) was calculated from the bulk density calculated and the particle density (2.65 Mg/m^3) taken as constant (Danielson and Sutherland 1986). The saturation percentage was determined by the procedure given by (Gardner 1986). Available water holding capacity was determined in soil samples of each plot through pressure

Table 2 Fertilizer treatments combination for cereal and legume crops

Treat-ment	Wheat N	Wheat P_2O_5	Wheat K_2O	Wheat FYM	Maize N	Maize P_2O_5	Maize K_2O	Maize FYM	Lentil N	Lentil P_2O_5	Lentil K_2O	Lentil FYM
T1	0	0	0	0	0	0	0	0	0	0	0	0
T2	60	45	0	0	60	45	0	0	15	22	0	0
T3	120	90	60	0	120	90	60	0	30	45	0	0
T4	60	90	60	20	60	90	60	20	15	45	0	20

N, P_2O_5, K_2O (kg/ha), FYM (tonnes/ha) membrane apparatus according to the procedure described by Raza *et al*. (2003).

The data collected was analyzed using ANOVA for RCB-design in MSTATC software. According to Steel and Torrie (1980), means of the data were calculated and the variation amongst means of different treatments/cropping systems/crop seasons was determined using LSD test. Correlation studies among different parameters of the soil analysis were carried out and the r^2 values were determined.

RESULTS AND DISCUSSION

Effect of fertilizer treatments on physical properties of soil

Analysis of the combined data over seasons revealed that fertilizer treatments effect on soil bulk density, porosity, saturation percentage and available water holding capacity (AWHC) was highly significant (P<0.01) both in surface (0-20 cm) and sub-surface (20-40 cm) soil. LSD test further revealed that all the treatment means were significantly different from one another at both depths (Table 3). Integrated use of FYM and mineral fertilizers (T4) recorded the lowest bulk density in both the surface and sub-surface (1.21 and 1.31 Mg/m^3, respectively) soil which subsequently resulted in the highest total porosity (54.1 and 50.4%, respectively), saturation percentage (36 and 29%, respectively) and available water holding capacity (AWHC-185 and 152 g/kg, respectively) while the control (T1) maintained the highest bulk density (1.37 and 1.42 Mg/m^3, respectively), lowest total porosity (47.7 and 47.2%, respectively), saturation percentage (28 and 26%, respectively) and AWHC (128 and 120 g/kg, respectively) in both depths. Farmyard manure might have improved organic matter content of soil directly thus making it more porous with less mass per unit volume. This treatment also produced highest biological yield (data not shown here) thus returning largest amount of leaves and stubbles to the soil that further increased soil organic matter content and decreased soil bulk density thereby increasing soil porosity. Increased soil organic matter might have encouraged aggregation and soil porosity thereby making more room available for soil water. These results confirmed the findings of Hati *et al*. (2006) and Khan *et al*. (2007) who reported improved physical properties with the integrated use of farmyard manure and chemical fertilizers. Farmyard manure, on its mineralization, might have released Ca^{2+} which encourages renewed flocculation and soil aggregation. The increased soil aggregation increase total porosity (Sanchez *et al*. 1989), which in turn increase saturation percentage, available water holding capacity, infiltration capacity, hydraulic conductivity and water stable aggregates and decrease bulk density and surface crusting in the soil (Haynes and Naidu 1998).

Increasing concentration of mineral fertilizers alone also showed significant reduction in bulk density and subsequent increase in total porosity, saturation percentage and AWHC as compared to the control in both depths (Table 3). Increased crop production with each increment of sole mineral fertilizer NPK also caused high root densities that in return enhanced soil aggregation and porosity as compared to the control plot. Thus, the effect of fertilizer treatments on the aforementioned properties was in the order of; T4>T3>T2>T1.

Effect of cropping patterns on soil physical properties

Cropping pattern affected the bulk density and total porosity of soil significantly (P<0.01) at both depths while

Table 3 Effect of fertilizer treatments and cropping patterns on soil physical properties at the experimental site

Parameters	Effect of fertilizer treatments									
	0-20 cm					20-40 cm				
	T1	T2	T3	T4	LSD (<0.05)	T1	T2	T3	T4	LSD (<0.05)
B. Density (Mg/m^3)	1.37	1.33	1.28	1.21	0.02	1.42	1.39	1.35	1.31	0.015
Porosity (%)	47.7	49.4	51.5	54.1	0.81	46.0	47.2	48.8	50.4	0.49
Saturation (%)	28	31	33	36	0.79	26	27	28	29	0.6
AWHC (g/Kg)	128	140	160	185	2.9	120	136	145	152	3.4
	Effect of cropping patterns									
		C1	*C2*	*C3*	*LSD (<0.05)*		*C1*	*C2*	*C3*	*LSD (<0.05)*
B. Density (Mg/m^3)		1.32	1.27	1.31	0.02		1.38	1.35	1.38	0.02
Porosity (%)		49.8	51.8	50.4	0.62		47.7	49.1	47.5	0.6
Saturation (%)		31.1	33.7	31.4	0.84		27.5	28.3	27.7	
AWHC (g/Kg)		150	158	152	2.76		138	136	140	

Treatments: T1=Control, T2= $N:P_2O_5:K_2O$ (60:45:0 kg/ha), T3= $N:P_2O_5:K_2O$ (120:90:60 kg/ha), T4= $N:P_2O_5:K_2O$ (60:90:60 kg/ha) + FYM (20 tonnes/ha). Data for fertilizer treatments has been combined from 4 seasons, 3 cropping patterns and 3 replications. C1=Maize-wheat-maize, C2=Maize-lentil-maize, C3=Maize-intercrop-maize. Data for cropping patterns has been combined from 4 seasons, 4 fertilizer treatments and 3 replications.

its effect on saturation percentage and AWHC was significant ($P<0.01$) in surface soil only. It was found that amongst the cropping patterns, the cereal-legume rotation showed significantly lower bulk density and significantly higher total porosity in surface soil as well as in sub-surface soil while the reverse was observed in cereal-cereal rotation (Table 3). This might also be attributed to higher organic matter content in legume based crop rotation than the one having sole cereals. The findings of Latif *et al.* (1992) support these results. He revealed that legume have significant effect on some soil physical properties. Monoculture cereals have lowest stability and smallest mean weight diameter of soil aggregates whereas legumes in crop rotation reduce bulk density and increase porosity.

Inclusion of legumes in the traditional cereal-cereal rotation improved the saturation percentage and AWHC and the cereal-legume rotation showed the maximum saturation percentage in both depths while cereal-cereal rotation showed the lowest saturation percentage in surface soil (Table 3). With regard to AWHC, data in Table 3 showed a trend similar to saturation percentage in surface soil while in sub-surface soil, the maximum AWHC was observed in cereal-legume intercrop whereas the minimum AWHC was observed in cereal-legume rotation. The basic rule of crop rotation is that a crop should never follow itself and the greatest benefit from crop rotation comes when crops grown in sequence are in totally different families. For example, the systems of cereal and legumes are excellent for building soil structure (OMAFRA 2009). Research in both the United States and Canada also indicated improved soil physical properties following legumes. The improvements are attributed to increases in more stable soil aggregates due to the protein and glomalin, along the roots of legumes, that serves as a "glue" and binds soil together into stable aggregates. This aggregate stability plus the aggressive taproot system reaching deep into the soil increases pore space, promoting air movement and water percolation deep into the soil (Auburn 1998).

Variation in physical properties with time (temporal variation)

Results shown in Table 4 revealed that soil bulk density, total porosity and saturation percentage was significantly ($P<0.01$) improved by the combined effect of fertilizer treatments and cropping patterns over time in surface soil (0-20 cm). Based on pooled data over fertilizer treatments and cropping patterns, it was observed that bulk density during *rabi* 2007 was 4.5% lower than *kharif* 2006 while increase in total porosity and saturation percentage during *rabi* 2007 over *kharif* 2006 was 4.2 and 21%, respectively (Table 4). There was a consistent trend of improvement in these parameters. The AWHC showed improvement to a non-significant extent in surface and the trend was also inconsistent. In sub-surface soil, only saturation percentage showed significant ($P<0.05$) and consistent improvement (11%) during *rabi* 2007 over *kharif* 2006 while the bulk density, total porosity and AWHC showed improvement to a non-significant extent along with an inconsistent trend with time.

Due to the gradual increase in organic matter with time due to application of farmyard manure, soil bulk density decreased and porosity, saturation percentage and available water holding capacity increased accordingly with time from *kharif* 2006 to *rabi* 2007. The decrease in bulk density as a result of organic manure addition might also be attributed to a dilution effect caused by mixing of this organic material with denser mineral fraction of the soil (Haynes and Naidu 1998). The decrease in bulk density with mineral fertilizer application, only, might be due to increased root density and above surface biological parts left over in soil that increased organic matter in the soil. It was also found that bulk density of the soil showed increasing trend with depth. Some process of clay movement down the profile and accumulation in sub-surface soil clog soil pores and decrease soil porosity and increase soil bulk density in sub-surface soil. Shafiq *et al.* (1988) and Khan *et al.* (2003) also reported that loose and porous top soil has lower bulk density than compact subsoil.

The analysis of cropping patterns effect over time based on combined data over fertilizer treatments showed that the improvement brought about by cropping patterns in the bulk density, soil total porosity and saturation percentage was significantly different from each other and that the cereal-legume rotation was superior amongst all the three cropping patterns in improving all the above soil physical parameters with time (Fig 1). Furthermore, the trend in the improvement was consistent with time. Cereal-legume rotation also improved the AWHC but to a non-significant extent and the trend of improvement was also inconsistent. Improvement in physical properties in this experiment correlate well with each other (bulk density vs saturation percentage r^2 = - 0.97 and bulk density vs AWHC r^2 = - 0.93). Highly significant negative correlation suggest that decrease in bulk density provided space for both saturation and available water thus causing their content to increase in eroded soils.

Table 4 Temporal variation in soil physical parameters at the experimental site

Depth (cm)	Physical properties	*Kharif* 2006	*Rabi* 2006	*Kharif* 2007	*Rabi* 2007	LSD (<0.05)
0-20	B. Density (Mg/m^3)	1.33	1.30	1.28	1.27	0.02
	Porosity (%)	49.5	50.4	51.2	51.7	0.71
	Saturation (%)	28.3	29.9	34.4	35.7	0.97
	AWHC (g/kg)	148	152	158	155	
20-40	B. Density (Mg/m^3)	1.37	1.38	1.37	1.36	
	Porosity (%)	48.2	47.7	48.2	48.4	
	Saturation (%)	25.9	28.3	28.2	29.0	1.12
	AWHC (g/kg)	131	140	144	138	

Data have been combined from 3 cropping patterns, 4 fertilizer treatments and 3 replications at each treatment

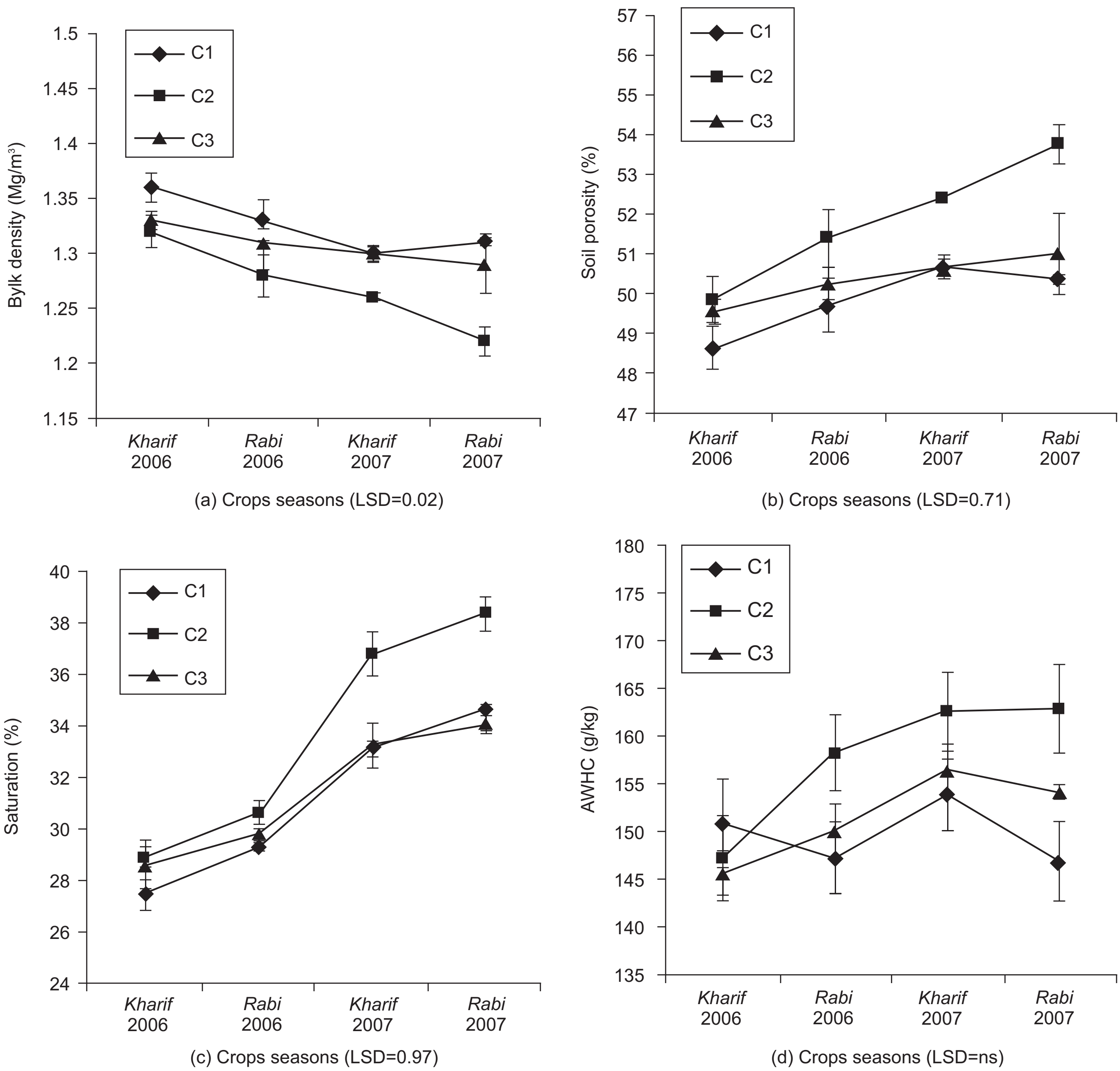

Fig 1 Effect of cropping pattern on soil (a) bulk density (b) porosity (c) saturation (d) available water based on combined data over seasons

From the data analysis it was further observed that crop seasons had significant ($P<0.01$) interaction with fertilizer treatments for all the above soil physical parameters in surface soil while in sub-surface soil, it was significant for bulk density ($P<0.01$), saturation percentage ($P<0.05$) and AWHC ($P<0.01$) only. The cropping seasons interaction with cropping patterns was significant for saturation percentage and AWHC in the surface soil only.

It was concluded that mixed application of farmyard manure and mineral fertilizers significantly improved soil physical environment over that of recommended dose of NPK fertilizer alone which suggest that the sole application of recommended NPK fertilizer cannot restore the physical environment of eroded soil to its maximum potential. Therefore, for sustainable agriculture on such soils, mixed application of farmyard manure and mineral fertilizers should be carried out. For this purpose, being an unstable nutrient element, recommended dose of mineral N must be reduced by 50% to avoid its over-application and subsequent toxicity. In addition to other benefits of legumes in rotation, its improvement of physical properties further assert their importance in farming on such eroded lands

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