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FACTOR ANALYSIS OF TILLAGE EFFECTS ON SOIL PROPERTIES OF GRANTSBURG SOILS IN SOUTHERN ILLINOIS UNDER CORN AND SOYBEAN

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Abstract

Adoption of conservation tillage resulted in changes in soil properties, soil organic matter, soil nutrients. These soil variables were strongly correlated and could not be explained independently by the univariate analysis. The objectives of the study were to use the factor analysis for the identification of the factor pattern in soil properties and to examine the changes in factor scores in no-till (NT), chisel plow (CP) and moldboard plow (MP) tillage systems at different depths after 8 years of the tillage application and planting of corn and soybean on a sloping and previously eroded with a root restricting fragipan Grantsburg soil. The soil samples from the 0 to -5 and -5 to -15 cm soil depths were analyzed for the Ca, Mg, K, P, aggregate stability, particulate organic C, N and humified organic C and N. With factor analysis, 13 highly correlated soil variables were grouped into three different uncorrelated factors, which accounted for the 78% total variance of the data. The soil organic factor had high variable loading on aggregate stability, soil organic C and N contents in soil, POM and humified organic fractions. This factor varied between tillage and represented the accumulation of soil organic matter and its effect on aggregation because of the adoption of tillage. The soil exchange factor had high variable loading for the extractable Ca, Mg and CEC, and varied with tillage and depth because of mixing due to plowing and stratification due to use of no-till treatment. The soil nutrient factor had high variable loading on soil K and P and soil pH and varied between tillage treatments. The nutrient factor scores were also affected by fertilizer application and its mixing by plowing in CP and MP. No-till, which lacks mixing, resulted in decrease in availability of nutrients. This technique enables us to combine the correlated soil variables into three different groups and assess the impact of soil management systems, soil depths and sampling years on these factors. In the NT, lack of tillage, resulted in stratification of exchangeable bases, reduced availability of nutrients. However, it contributed to the maintenance of soil organic matter and soil aggregation. The mixing of soil with plowing resulted in the uniform nutrient availability and exchange capacity of soil in plow layer with the CP and MP systems. The plowing affected soil aggregation adversely due to decomposition of soil organic matter and making soil more susceptible to erosion. The crop yield of maize and soybean were higher with NT system than with CP and MP systems.

Introduction

Adoption of conservation tillage protected previously eroded soils from erosion by leaving the crop residue on the soil surface, maintaining soil organic C and soil aggregation. In tillage studies, the effect on soil properties was mainly dependent upon the type and intensity of tillage. No till (NT) practice resulted in the accumulation of soil organic C and nutrients in the soil surface, whereas the moldboard plowing (MP) distributed the nutrients more evenly into the tillage zone and reduced the soil organic matter (Karlen *et al.,* 1991; Ismail *et al.,* 1994). These changes in soil properties due to different tillage practice became relatively stable with the passage of time.

The soil properties were observed to explain the overall impact of different tillage systems on soils and these were highly correlated with each other. Cation exchange capacity (CEC) of soil was mainly affected by the soil texture, amount and type of clay minerals and organic matter (Arshad & Coen, 1992), so changes in soil organic C could affect CEC of soil (Mahboubi *et al*., 1993). Exchangeable cations could be correlated with the CEC and soil pH, and availability of nutrients could be affected due to the changes in soil pH. Soil organic matter contents and its different fractions affect the aggregate stability of soil which is important in soil protection against erosion. Aggregate stability was correlated with the ratio of mineral associated to total organic matter C and N (Bear *et al.*, 1994). Organic matter also increased the solubility of soil phosphorus (P) and ultimately increased its availability to crop plants.

The existence of strong correlation between different soil properties complicated the interpretation of the changes due to different tillage systems, and the results could not be explained well with the univariate analysis. This problem could be resolved with the use of multivariate analysis. In multivariate analysis, the data set with more than one response variable for each observational or experimental unit were analyzed simultaneously (Venables & Ripley, 1994). Multivariate analysis was used as a tool for studying the complex relationship of highly correlated variables. The technique provided an opportunity to make firmer conclusions which could not be made with the univariate analysis of highly correlated soil variables.

Factor analysis was the one of the multivariate analysis techniques that considered variables simultaneously and groups the highly correlated variables into un-correlated factors (Brejda, 1998). Factor analysis decomposed the correlation matrix of correlated variables into the variance attributed to factors. These factors were a combination of a set of soil variables. Each factor became a new variable and the retained factors explained the maximum variance (Sharma, 1996). The first factor accounted for as much variation in the data as possible and each succeeding factor accounts for as much of the remaining unaccounted variation by preceding factors as possible. Factor analysis identified the underlying factors, which are responsible for the correlation among the variables (Sharma, 1996) and revealed the complex relationship of soil variables for the better interpretation of data (Brejda, 1998) which was not possible with the univariate data analysis.

The objective of this study were to use the factor analysis for the assessment of changes in selected soil properties by: (i) identifying the factor pattern in soil properties with different tillage and (ii) to examine the changes in factor scores with tillage systems, no-till, chisel plow and moldboard plow at different depths after 8 years of the experiment on a sloping and previously eroded with a root restricting fragipan Grantsburg soil.

Materials and Methods

Background of study site: A tillage experiment was started on April 12, 1989, at the Dixon Springs Agricultural Research Center in Southern Illinois, USA. The experiment site was a forest that was cleared and cultivated in the 1860s and remained under cultivation until about 1974. Afterwards this area with an average slope of 6% had been dominated with tall fescue (*Festuca arundinacea* (L.)) for more than 10 years prior to the start of this experiment.

The soil in the study site was a moderately well drained, Grantsburg (fine-silty, mixed, mesic Typic Fragiudalf) silt loam with an average depth of 64 cm to a root restricting fragipan. Grantsburg soils were formed in loess under forest vegetation and underlain at a depth of 2 to 5 m by siltstone. On April 12, 1989 lime ($CaCO_3$) with 94% calcium carbonate equivalent, @ 3.1, 4.9, and 7.3 Mg/ha, was applied on upper, middle, and lower rows, respectively to adjust the soil pH. Three tillage treatments, moldboard plow (MP), chisel plow (CP), and no-till (NT), were established on April 27, 1989. The experimental design was a Complete Latin Square with two squares. Each square had three rows and three columns. Each treatment was randomized 6 times in 18 plots and these plots were rectangular 9 m x 12 m in size. Therefore, for approximately 115 years the area was cultivated and eroded which explains the moderately eroded Grantsburg soil that was in sod in 1989 prior to the application of the tillage treatment.

Field activities and tillage operations: Starting with corn in 1989, corn and soybean was planted in alternate years. On April 6, 1995 moldboard plowing and chiseling was performed. Before planting, 50 kg/ha of nitrogen and 55 kg/ha of phosphorus in the form of diammonium phosphate (18-46-0), and 232 kg/ha of potassium in the form of potassium chloride (0-0-60) were broadcast on all plots. Corn (Pioneer Hybrid 3394) was planted @ 64,220 seeds/ha on May 31, 1995. Nitrogen in the form of anhydrous ammonia was knifed in @ 168 kg/ha of nitrogen on June 26, 1995 and the crop was harvested on October 6, 1995.

Plowing and chiseling in combination with disking were performed on June 5, 1996. No fertilizer was applied during the 1996 growing season. Soybean (Pioneer Brand 9382) was planted @ 432,250 plants/ha on June 5, 1996. Later in the season, Roundup @ 2.33 liter/ ha was sprayed on July 2, 1996. Crop was harvested on October 18, 1996.

Soil sampling and laboratory analysis: At the initiation of the trial, soil samples were taken from 0 to -5 and -5 to -15 cm depths for the determination of soil pH, CEC, Bray P-1, extractable K, Ca, and Mg, aggregate stability and soil organic C. Soil samples were also taken at 25 days after planting in 1995 and 1996 growing seasons at the 0 to -5 and -5 to -15 cm depths for the determination of soil pH, CEC, Bray P-1, extractable K, Ca, and Mg, aggregate stability and soil organic C and N in different fractions of soil. Soil cores were collected from each corner and center of plots between the rows and were composited. The samples were air-dried, crushed mixed, and passed through 2-mm sieve.

Soil pH was determined using 1:1 soil water ratio. Extractable soil phosphorus was measured using Bray P-1 method (Kundsen & Beegle, 1988) and the Standard Soil Scoop Method described by Peck (1988). Exchangeable Ca, Mg, and K were extracted by 1N NH_4OAc (pH = 7.0). Calcium and Mg were determined by atomic absorption (Lanyon & Heald, 1988). Extractable K was determined by atomic emission (Kundson *et al.*, 1982) on a Perkin-Elmer Model 2380 atomic absorption (AA) spectrophotometer. Cation exchange capacity (CEC) was measured using ammonium saturation method (Chapman, 1965) and subsequent diffusion of ammoniacal nitrogen (Mulvaney, 1996). Soil aggregate stability was determined by wetting the 25 g soil sample on a 250 µm screen for 10 minutes and subsequent wet sieving for 10 minutes (Kemper & Rosenau, 1986).

Particulate organic matter (POM) was determined by the method described by Cambardella & Elliot (1992). Ten grams of soil (<2 mm) sample was dispersed in 30 ml of 5 g L^{-1} Sodium hexametaphosphate by shaking on a reciprocal shaker for 18 hours. The dispersed material was sieved through the 53 µm sieve and rinsed several times in a beaker. The soil slurry in the beakers was dried at 50^oC in a forced air oven. Dried samples, obtained from soil slurry, were ground and analyzed for organic C and N and this fraction was identified as humified organic C and N. The material retained on the sieve was particulate organic matter and its values were obtained by subtracting mineral associated fraction from soil organic C and N values. Organic C and N for soil and humified samples were determined by using LECO CNS-2000 Carbon, Nitrogen and Sulfur Analyzer.

Statistical analysis: Statistical analysis was performed on the data using the procedures from Statistical Analysis System (SAS) computer software (SAS Institute, 1995). In Univariate analysis, least square means and analysis of variance for all parameters were calculated by General Linear Model (GLM) procedure using Latin Square Design with year as a factor. The least square means were obtained from tillage × year interactions.

The correlation among the soil variables aggregate stability, soil organic C, soil organic N, POC, PON, humified organic C, humified organic N, extractable K, Ca, Mg, and P, cation exchange capacity and pH by PROC CORR procedure. Factor analysis of the data was performed by PROC FACTOR method with varimax rotation (SAS Institute, 1995; Brejda, 1998). To avoid the effect different measurement units of soil variables in factor loading, the analysis were performed on the correlation matrix. Factors were extracted with the principal component analysis method and three factors with the eigen values of >1 were rotated orthogonally with the specifications of varimax rotation. The variance of each factor is redistributed in a way that each factor loads highly on one factor with close to zero loading on the others with the varimax rotation. Rotated factor loadings were used for the selection of a set of soil variables for each factor.

Rotated factor scores, which are linear transformations of the original soil variables and are the estimates of values for factors, were calculated using the PROC SCORE method. Rotated factor score were analyzed by analysis of variance using the complete Latin square design with square row column and year as random effects and tillage and depths as fixed effects. F-test for each effect was performed with appropriate expected mean square and error term. The least square means for all rotated factor scores were calculated tillage × depth interactions.

Results and Discussion

At the initiation of tillage treatments, non significant differences in all soil property data like soil pH, CEC, extractable Ca, Mg, P and K, AS and SOC were observed in all plots in -5 to -15 cm soil layer (Table 1). However, extractable P was higher with CP and extractable K in NT plots in comparison with other tillage plots in 0 to -5 cm depth. Soil organic carbon was higher in NT plots followed by CP and MP in 0 to -5 cm depth (Table 1).

Table 1. Base line soil properties in year 1 (July 1989) at two depths after different tillage operating.

Soil variable	pH	Ca mg g^{-1}	Mg mg g^{-1}	K mg kg^{-1}	P mg kg^{-1}	AS# %	CEC# cmole kg^{-1}	SOC# g kg^{-1}
			Depth		**0-5cm**			
No-till	6.5a*	1.77a	0.15a	119a	28ab	31a	17.2a	17.5a
Chisel plow	6.7a	1.80a	0.14a	102b	34a	24a	18.3a	15.3b
Moldboard plow	6.0b	1.60a	0.14a	75c	22b	25a	19.5a	10.8c
			Depth		**5-15cm**			
No-till	6.3a	1.70a	0.16a	53a	7a	25a	18.3a	11.8a
Chisel plow	6.2a	1.70a	0.15a	55a	9a	18a	18.3a	11.9a
Moldboard plow	6.4a	1.70a	0.16a	62a	8a	20a	17.8a	12.3a

*For each parameter, means at the same depth followed by a same letter are not significantly different at the p=0.05 probability level. # Aggregate stability (AS); cation exchange capacity (CEC); soil organic carbon (SOC).

After 8 years of continuous NT, CP and MP, soil pH and extractable Ca was significantly higher in the NT system as compared to the CP and MP systems in the 0 to -5 cm soil layer (Table 2). In -5 to -15 cm soil layer, tillage effects were not significantly different for on soil pH, extractable Ca and Mg, whereas extractable Mg was significantly higher in the CP and MP than NT system in -5 to -15 cm depth. Soil extractable K and P were higher with the CP system than the NT and MP systems. Mixing of soil due to moldboard plow and chisel plow resulted in higher soil extractable K and P in the -5 to -15 cm soil layer than the NT. The cation exchange capacity values were higher with NT in 0 to -5 cm soil layer; however, the differences due to tillage were non-significant in both 0 to -5 and -5 to -15 cm soil layers (Table 2). Aggregate stability was higher in the NT system than the CP and MP systems in both 0 to -5 and -5 to -15 cm soil layers due to higher organic C, lack of tillage, and slow rate of decomposition (Hussain *et al*., 1999). Organic C and N in soil, particulate organic matter (POM) and humified organic matter (HOM) fraction were in order of NT > CP > MP in the surface soil layer of 0 to -5 cm. However, the differences in organic C and N in soil, POM and HOM were non-significant with different tillage systems.

Table 2. Effects of 8 years of tillage operating on selected soil properties at two depths.

Soil variable	pH	Ca mg kg^{-1}	Mg mg kg^{-1}	K mg kg^{-1}	P mg kg^{-1}	AS# %	CEC# cmole kg^{-1}	SOC# g kg^{-1}	SON# g kg^{-1}	HOC# g kg^{-1}	HON# g kg^{-1}	POC# g kg^{-1}	PON# g kg^{-1}
						Depth		**0-5cm**					
No-till	6.42a*	2.41a	0.17a	212c	48.3a	31a	18.0a	18.69a	1.89a	11.56a	1.36a	7.12a	0.53a
Chisel plow	6.14b	2.02b	0.17a	250a	51.4a	18b	17.3a	15.41b	1.60b	9.87b	1.20b	5.54b	0.40ab
Moldboard plow	6.21b	1.94b	0.16a	227b	34.6b	14b	17.3a	12.97c	1.37c	8.92c	1.08c	4.05c	0.29b
						Depth		**5-15cm**					
No-till	6.24a	1.94a	0.14b	125b	8.6b	26a	15.7a	11.27a	1.22a	8.33a	0.98a	2.94a	0.24a
Chisel plow	6.25a	2.01a	0.18a	151a	11.6a	15b	16.2a	11.14a	1.22b	8.13a	0.99a	3.04a	0.23a
Moldboard plow	6.30a	1.98a	0.18a	160a	13.9a	15b	16.3a	10.92a	1.16a	7.68a	0.93a	3.24a	0.23a

*For each parameter, means at the same depth followed by a same letter are not significantly different at the p=0.05 probability level.

Aggregate stability (AS); cation exchange capacity (CEC); soil organic carbon (SOC); soil organic nitrogen (SON); humified organic carbon (HOC); humified organic nitrogen (HON); particulate organic carbon (POC) and particulate organic nitrogen (PON).

Humified organic matter with narrow C/N ratio (8.2 to 8.5) had more humified organic C and more stable than POM fraction in both surface and sub surface layers. Wider C/N ratio with MP in comparison with NT and CP in both soil layers could be due to incorporation of root and residue in plow layer. Wider C/N ratio of humified fraction in NT could be due to the presence of some labile organic C in the humified organic fraction in the sub-surface soil of -5 to -15 cm (Table 2).

Significantly high (p = 0.05) correlation was observed in 57 out of total 78 pairs of soil variables (Table 3). All significant correlations were positive. Extractable Mg was negatively correlated with soil pH (r^2 = 0.23) and aggregate stability (r^2 = 0.25). Cation exchange capacity was highly correlated with the extractable Ca, Mg, and K. Only a few of the variables had a significant correlation with pH (Table 3). Soil pH was significantly correlated with extractable Ca, humified organic C and extractable Mg with the correlation coefficients of <0.30. Aggregate stability was positively correlated with exchangeable Ca, SOC, SON, POC, PON, HOC and HON.

In the process of factor selection, some were chosen on the basis of: (i) the eigen values of >1 and (ii) more than one soil variable with the highest factor loading (Table 3). Eigen values, which correspond to each of the components, represent a partition of the total variation. The sum of all eigen values is equal to the sum of all variable variances if the covariance matrix is used, and to the number of variables if the correlation matrix is used (Anon., 1995). The fourth factor only explained soil pH with the eigen value of >1, so the fourth factor was not considered and further analysis were only performed on three-factor model.

Three factor model had the eigen values of 6.47, 2.34 and 1.38 and explained 78.3% variance of all soil variables (Table 4). The proportion of variance of each soil variable explained by the model is estimated by the communalities. The values of communalities showed that three factor model accounted for >90% variance of exchangeable Ca, SOC and SON, >80% of extractable Mg, K and P, HOC and POC and, >70 % of HON and PON, and >60% of cation exchange capacity and aggregate stability (Table 4). In three factors model, 30% variance of soil pH was explained, which means that a large proportion of variance in soil pH could not be explained by this model. The correlation coefficients for soil pH with other variables were smaller which could be the reason for its low communality value. Due to low communalities, soil pH would be given less importance while describing the results on the basis of factors.

Table 3. Correlation between selected soil properties of grantsburg soil.

Soil variable	pH	Ca	Mg	K	P	AS#	CEC#	SOC#	SON#	HOC#	HON#	POC#	PON#
Soil pH	1.00												
Extractable Ca	0.30*	1.00											
Extractable Mg	-0.23*	0.52*	1.00										
Extractable K	-0.12	0.24*	0.32*	1.00									
Extractable P	-0.06	0.21	0.08	0.88*	1.00								
Aggregate stability	0.12	0.30*	-0.25*	-0.25	0.02	1.00							
CEC	-0.17	0.48*	0.54*	0.53*	0.45*	-0.03	1.00						
Soil organic C	0.17	0.52*	-0.04	0.42*	0.61*	0.52*	0.39*	1.00					
Soil organic N	0.15	0.52*	-0.03	0.47*	0.64*	0.48*	0.41*	0.98*	1.00				
Humified organic C	0.21*	0.58*	0.02	0.47*	0.64*	0.44*	0.42*	0.86*	0.87*	1.00			
Humified organic N	0.16	0.55*	0.06	0.55*	0.68*	0.34*	0.45*	0.81*	0.84*	0.98*	1.00		
POC	0.10	0.37*	-0.09	0.31*	0.48*	0.49*	0.29*	0.92*	0.88*	0.59*	0.53*	1.00	
PON	0.13	0.32*	-0.10	0.22*	0.38*	0.50*	0.21	0.83*	0.81*	0.47*	0.39*	0.95*	1.00

*Significant at the 0.05 probability level

Aggregate stability (AS); cation exchange capacity (CEC); soil organic carbon (SOC); soil organic nitrogen (SON); humified organic carbon (HOC); humified organic nitrogen (HON); particulate organic carbon (POC) and particulate organic nitrogen (PON).

(Correlations are pooled across different tillage and soil depths and years (n = 72).

Table 4. Rotated factor loading and communalities of a 3-factor model of soil properties under different tillage systems and depths.

Soil variable	Factor loadings			Communalities
	Factor 1	Factor 2	Factor 3	
pH	0.19	0.05	-0.51	0.30
Extractable Ca	0.41	0.80	-0.32	0.91
Extractable Mg	-0.20	0.86	0.16	0.81
Extractable K	0.42	0.34	0.77	0.89
Extractable P	0.65	0.16	0.66	0.88
Aggregate stability	0.57	-0.10	-0.56	0.65
Cation exchange capacity	0.29	0.69	0.34	0.68
Soil organic C	0.98	0.15	-0.02	0.98
Soil organic N	0.97	0.17	0.03	0.97
Humified organic C	0.84	0.32	0.03	0.82
Humified organic N	0.80	0.35	0.14	0.78
Particulate organic C	0.90	-0.01	-0.06	0.81
Particulate organic N	0.83	-0.08	-0.14	0.72
Eigen values	6.47	2.34	1.38	

Proportion of variance	46.1	17.6	14.5

The simple correlation between the original soil variables and the factors are known as the factor loading, which were used for the grouping of soil variables into factors. Aggregate stability (AS), soil organic carbon (SOC), soil organic nitrogen (SON), humified organic carbon (HOC), humified organic nitrogen (HON), particulate organic carbon (POC) and particulate organic nitrogen (PON) accounted for 46.2% variance from all soil variables and were grouped in the first factor. The first factor had high factor loading of 0.80 to 0.98 for, SOC, SON, HOC, HON, POC and PON and moderate factor loading of 0.65 and 0.57 for extractable P and aggregate stability, respectively. This soil organic factor is aggrading and explained the different fractions of soil organic matter, which contribute toward soil stability, aggregation and resistance of the soil erosion. The highest factor loading for 7 soil variables represented the changes in soil organic matter due to tillage.

Soil organic factor scores were significantly affected with different tillage systems and tillage depth (Table 5). Soil organic factor score were significantly different in the order of NT > CP > MP system, in 0-5 cm soil layer (Table 6). Higher amount of organic C and N in POM and HOM of organic matter and aggregate stability with the NT as compared to the CP and MP systems contributed towards high factor scores in the 0 to -5 cm soil layer. In the -5 to -15 cm soil layer, all the tillage systems had negative factor score but the score with the NT system was higher than other systems. The negative soil organic factor score with different tillage in -5 to -15 cm soil layer were due to the too lower amount of organic C and N in sub-surface soil (Table 2). Whereas higher factor score with the NT could be attributed to significant aggregate stability due to non-disruption of aggregates. The moderate loading for extractable P with the first factor indicated that the organic matter could have an effect on the availability of soil P and plant growth. Higher soil organic factor score with the NT pointed toward the fact that the NT system created favorable environment for accumulation of organic matter and soil aggregation. Apparently, tillage disrupted the macro aggregates, depleted particulate organic matter and resulted in enhancement of soil erosion in the MP system. This factor is supported by the erosion rate data that showed on the Grantsburg soil with 5-7% slopes, the estimated annual soil loss, measured with USLE, was 8, 21 and 30 Mg ha^{-1} with the NT, CP and MP systems, respectively (Walker & Pope, 1983).

Extractable Ca and Mg, and CEC accounted for 17.7% variance from all soil variables and were grouped in the second factor. This soil exchange factor had high variable loading of 0.80, 0.86 and 0.69 for extractable Ca and Mg and CEC (Table 4). The grouping of extractable Ca, Mg and CEC in this factor was due to the fact that extractable Ca and Mg accounted for the dominant part of cation exchange capacity and were positively correlated were with CEC. Mixing of clay contents from the sub-surface due to tillage might be the reason for variations in exchange factor score with tillage × depth (Table 5). The exchange factor scores were significantly higher and positive with the NT system than the MP and CP in the 0 to -5 cm soil layer. The CP and MP systems had significantly higher positive exchange factor scores in the -5 to -15 cm soil layer than NT (Table 6). Higher positive exchange factor score with the NT in the 0-5 cm soil layer indicated the stratification or accumulation of exchangeable bases due to lack of tillage. The higher exchange factor score with the CP and MP in the -5 to -15 cm layer were due to more uniform mixing of soil to the -15 cm plow depth and their availability to crop plants.

Table 5. Analysis of variance and mean squares for the effects of tillage systems at two depths and two sampling years.

Source of variation	df	Factor 1	Factor 2	Factor 3
Square	1	0.723*	0.158	1.391*
Row	2	0.643*	13.037*	0.323
Column	2	0.114	4.500*	0.463
Year	1	0.183	6.859	5.747
Tillage	2	6.631*	0.022	7.472*
Year H tillage	2	0.211	0.057	0.623
Depth	1	37.749	0.714	15.573
Year H depth	1	0.699*	0.224	16.690*
Tillage H depth	2	3.091*	2.576	1.522
Year H tillage H depth	2	0.154	0.180	0.402
Error	55	0.181	0.405	0.181
R-square		0.86	0.69	0.86

* Significant at p=0.05

Table 6. Effect of tillage on factor scores for different tillage systems at two depths.

	Factor 1	Factor 2	Factor 3
Tillage	Depth	0-5 cm	
No-tillage	1.64a	0.47a	-0.44b
Chisel plow	0.66b	-0.09b	1.02a
Moldboard plow	-0.13c	-0.08b	0.81a
Tillage	Depth	5-15 cm	
No-tillage	-0.54a	-0.47b	-0.85b
Chisel plow	-0.77a	0.16a	-0.40a
Moldboard plow	-0.87a	0.22a	-0.14a

*For each factor, score means in the same column and depth followed by a same letter are not statistically significant at the p=0.05 level

The third factor had highest factor loading for soil pH, extractable K and P and accounted for 14.5% variance of total soil variables (Table 4). This soil nutrient factor had factor loading of 0.77, 0.66 and B0.51 for soil extractable K and P, and soil pH, respectively (Table 4). The presence of aggregate stability in third factor with moderate loading pointed towards a lack of interrelation. There was no significant correlation among soil pH, extractable K and P, but this grouping suggested the relationship between soil pH and availability of nutrients to crop plants.

Nutrient factor scores varied significantly between different tillage systems and sampling years (Table 5). The significant differences in sampling years could be due to differences in the fertilizer application and uptake by crop plants. At the end of 8 years of tillage experiment, the nutrient factor scores were significantly higher with the CP and MP than the NT system in 0 to -5 and -5 to -15 cm soil layers (Table 6). The nutrient factor scores were positive with the CP and MP in the 0 to -5 cm soil layer but scores were negative in -5 to -15 cm soil layer. Lower nutrient score in the NT could be explained by one or combination of the reasons such as: (i) fixation of soil K due to higher amount of Ca, (ii) leaching of K due to its higher mobility with the presence of continuous pores, and (iii) lower soil P availability due to relatively high pH. However, higher factor scores with the MP and CP could be explained with the uniform mixing of fertilizer into the 15 cm soil layer with the moldboard plowing and chiseling plowing.

Conclusions

Factor analysis was applied to estimate the changes in soil properties of previously eroded Grantsburg soil with adoption of different tillage systems crops (corn and soybean). The presence of correlation among soil properties make them dependant on each other and the changes can not be explained well with the individual analysis of soil properties. Factor analysis has the ability to take the correlation in to account and explain the variables simultaneously, so the technique was used to explain the changes by developing three un-correlated factors from 13 highly correlated soil variables. The effects of different measurement units on factor loading were eliminated by performing analysis on correlation matrix. The varimax rotation provided rotated factor which were orthogonal to each other and helps in identifying the independent effects of tillage on soil properties.

Factor analysis revealed that 8 years of continuous NT, CP and MP system on previously eroded soils, organic C and N in different fractions of soil organic matter and aggregate stability was affected positively with the NT system. Lack of tillage and accumulation of organic C could have contributed towards the better soil exchange factor (exchangeable bases and CEC) with the NT than MP and CP systems in soil surface. Lack of tillage in the NT resulted in stratification of exchangeable bases, reduced availability of nutrients for crop plants; however, it contributed to the maintenance of soil organic matter and soil aggregation. The mixing of soil with plowing resulted in the uniform nutrient availability to plants and exchange capacity of soil in plow layer with the CP and MP systems. The plowing affected soil aggregation adversely due to decomposition of soil organic matter and soil became more susceptible to erosion. Crop yield of corn and soybean were higher with NT system. No till system appeared to have resulted in improved crop productivity as compared to CP and MP systems.

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