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Effect of Tillage on Nonpoint Source Pollution of Surface and Ground Water System (I) : Effect of Tillage Practices on Density and Saturation of Soil

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Abstract□Increasing national concern on nonpoint source pollution of surface and ground water systems has led researchers and policy makers to develop certain agricultural Best Management Practices. As an initial step of broad study program above mentioned, this study reflected the effects of different tillage practice on bulk density and degree of saturation on two regional soils, namely Tama silt loam and Catlin silt loam. Results may help to clarify some of the conflicting findings on the impact of tillage systems on these parameters and it may also explain some of the reasons for specific role that different tillage systems play regarding nonpoint source pollution from agricultural fields.

Keywords□Nonpoint source pollution, best management practice, tillage treatment, bulk density, degree of saturation, moisture content, soil profile, specific gravity.

I. Introduction

The certain agricultural Best Management Practices(BMPs) may just be in the form a particular conservation tillage of that coupled with other erosion control practices such as contouring, terracing and/or building diversions in a accordance with increasing national concern on nonpoint source pollution of surface and ground water system.

Quantity and quality of water moving via various components of the hydrologic cycle is often associated with the land use(1, 15, 4, 8). Association of water quality and quantity to land use or tillage practices have often been explained in a direct manner rather than presenting the cause and effect relationships. Limited literature is available on how different tillage practices affect the soil physical and hydraulic properties and as a result they influence the water and chemical transport through porous media. Hill et al.[7)] reported that the soil under conservation tillage retained more plant available water and maintain higher unsaturated hydraulic conductivity than the comparable soils under conventional tillage systems. Kenny and Saxton[9)] measured soil bulk density under different tillage systms. Their results indicated mean bulk density patterns to be no-till〉chisel-disk〉plow-disk〉moldboard plow. Hill and Cruse [6)]. showed that tillage treament did not have significant effect on bulk density but bulk density increased with depth of all tillage practices. Cornbelt soils under no-till treatments showed significantly higher bulk densities[5, 10]. However, most research findings indicating the impact of conventional and conservation tillage systems on bulk density are not consistent.[2, 3, 5, 12, 16]

To evaluate the impact of different tillages or cover conditions on hydrologic and water quality responses many studies have been conducted using rainfall simulators. Generally, a simulation routine of dry run, wet run and very wet run has been conducted. Very wet run has been referred to as complete saturation or near saturation conditions[14]. Degree of saturation has never been investigated in the literature. Thorough assessment of the degree of saturation may assist in proper evaluation of soil hydraulic and hydrologic responses.

The objective of this study is to reflect the impact of different tillage practices on bulk density and degree of saturation on two Midwest soils namely Tama silt loam and Catlin silt loam (both of fine-silty, mixed, mesic Typic Arguidolls). Results may help to clarify some of the conflicting fingings on the impact of tillage system on these parameters and it may also explain some of the reasons for specific role that different tillage systems play the regarding nonpoint source pollution from agricultural fields.

II. Materials and Methods

Rainfall simulations were conducted in 1982 and 1983 on a Catlin silt loam soil and in 1984 and 1985 on a Tama silt loam soil. The Catlin soil with an approximately 5% slope was treated with 8 different tillage systems. The Tama soil with 7 to 12% slope was treated with 10 different tillage systems(Tables 1 and 2).

Each tillage system in the Table 1 consisted of contour and up-and-down hill practices so that 10 tillage treatments were implemented on the Tama soil. Disk and sweep plow were directed to only contour practices but others were subject to both contour an up-and-down hill practices so that 8 tillage treatments were practices on the Catlin soil(Table 2).

Each experimental plot was divided into two subplots which were treated with the same tillage practices. Two to four replicate suboplots were made for each tillage treatment. Each subplot measured about 11m long by 3m wide. Using a rotating-boom rainfall simulator, approximately 63 mm/h rain was applied. A simulation of dry, wet and very wet run was conducted on the Tama soil. Each test consisted of 1 hour rainfall (Dry run) followed by a 1 hour break. A second half rainfall (wet run) application was then applied followed by a short data collection pause and then a third half hour rainfall(very wet run) application. For catlin soil, a simulation was continued until a constant rate of runoff was observed for approximately 20 min. Each of these simulated rainfall events were applied to plots immediately after planting and then approximately one month later.

Data collected included soil bulk density, soil moisture before and after each run, and other parameter such as runoff rate, sediment concentration, residue and canopy cover and so on. All field operations and soil characteristics of each soil were summarized on Tables 1, 2, 3 and 4, respectively. Data collected were stored on Lotus 123 files.

These data were prepared to easy forms or manipulated to compute degrees of saturation of each soil. Specific gravity (Gs) of each soil was assumed to be 2.60. The data were transferred to SAS

Table 1. All field operations for tillage systems on Tama silt loam soil

Season	Field operation	Tillage systems				
		Mold-board	Chisel	Ridge-till	Strip-till	No-till
1981	Conventional, Soybeans(Wells II), All areas					
1982	Conventional, Soybeans(Wells II),All areas					
Spring, 83	Conventional, Corn(Sieben 68×5), All areas					
Fall, 83	Harvest corn	×	×	×	×	×
	Chisel plow		×			
	Moldboard plow	×				
Spring, 84	Apply lime(3.4 t/ha)	×	×	×	×	×
	Remove residue			×		
	Apply fertilizer(0−100−200)	×	×	×	×	×
	Ridge plow			×		
	Replace residue			×		
	Disk with harrow	×	×			
	Field cultivate with harrow	×	×			
	Rotary till				×	
	Plant soybeans(Century)	×	×	×	×	×
	with amiben(2.8 kg/ha)					
	and furaden(1.1 kg/ha)					
	Apply lasso(7 l/ha)	×	×	×	×	×
84∼6	Rainfall simulator test	×	×	×	×	×
84∼7	Rainfall simulator test	×	×	×	×	×
Fall, 84	Cultivate to form ridges			×		
	Harvest soybeans	×	×	×	×	×
	Disk and harrow				×	
	Seed wheat				×	
	Moldboard plow	×				
	Chisel plow		×			
Spring, 85	Apply anhydrous ammonia(202 kg/ha)	×	×	×	×	×
	Field cultivate with harrow	×	×			
	Field cultivate with harrow	×	×			
	Apply paraquat (2 l/ha)			×	×	×
	Plant corn with counter(9.8 kg/ha)	×	×	×	×	×
	Apply lasso (7 l/ha)					
85∼6	Rainfall simulator test	×	×	×	×	×
85∼7	Rainfall simulator test	×	×	×	×	×

data set for a statistical mean comparison procedures. Duncan's multiple-range test with a significance level of 5% was used. Means were presented without comparing with other means if less than 4 observations were made. SAS version 6.02 for personal computers was used for the statistical analyses.

Table 2. All field operations for tillage systems on Catlin silt loam soil

Season	Field operation	Tillage systems				
		Mold-board	Disked	Sweep plow	Sub-soil ridge	No-till
Fall, 80	Harvest corn	×	×	×	×	×
	Moldboard plow	×				
	Disk		×			
	Chop stalk			×		
	Sweep plow			×		
	Subsoil and ridge				×	
Spring, 81	Disk	×	×	×		
	Disk	×	×	×		
	Field cultivate	×	×	×		
	Reshape ridges				×	
	Plant soybeans	×	×	×	×	×
Fall, 81	Harvest soybeans	×	×	×	×	×
	Broadcast fertilizer (66 lb/ac P205, 67 lb/ac K20)	×	×	×	×	×
	Chisel	×				
	Sweep plow			×		
	Subsoil and ridge				×	
Spring, 82	Apply anhydrous ammonia (225 lb/ac)	×	×	×	×	×
	Disk	×	×	×		
	Disk	×		×		
	Field cultivate	×	×	×		
	Reshape ridges				×	
	Rotary till				×	
	Plant corn	×	×	×	×	×
82~6	Rainfall simulator test	×	×	×	×	×
	Cultivate one half plots	×	×	×	×	×
82~7	Hainfall simulator test	×	×	×	×	×
Fall, 82	Rarvest corn	×	×	×	×	×
	Broadcast fertilizer (68 lb/ac P205, 127 lb/ac K20)	×	×	×	×	×
	Disk	×	×			
	Moldboard plow	×				
	Chop stalks			×	×	
	Sweep plow			×		
	Subsoil and ridge				×	
	Chop stalks					×
Spring, 83	Disk	×	×	×		
	Disk	×	×	×		
	Field cultivate	×	×	×		
	Reshape ridges				×	
	Plant soybeans	×	×	×	×	×
83~6	Rainfall simulator test	×	×	×	×	×
	Cultivate	×	×	×	×	
83~7	Rainfall simulator test	×	×	×	×	×

Table 3. Soil interpretation record for Tama silt loam soil (Fine-silty, mixed, mesic Typic Arguidolls)

Particle size distribution :		
Sand :	2~0.05 mm	2.6%
Coarse silt :	0.05~0.02 mm	47.4%
Fine silt :	0.02~0.002mm	31.7%
Clay :	< 0.002mm	18.3%
Organic matter : 2.21%		

Table 4. Soil interpretation record for Catlin silt loam soil (Fine-silty, mixed, mesic Typic Arguidolls)

Particle size distribution :		
Sand :	2~0.05 mm	5~10%
Coarse silt :	0.05~0.02 mm	25~30%
Fine silt :	0.02~0.002mm	30~35%
Clay :	< 0.002mm	~25%
Organic matter : 3~4%		

Ⅲ. Results and Disscussion

Data obtained in this study were analyzed to examine the impact of different tillage systems on bulk density and degree of saturation for both Tama and Catlin soils. Changes in bulk density, and degree of saturation with time and profile depth were also examined.

1. Bulk density

Figs. 1~5 show the impact of tillage, depth, time of year, and winter cover on bulk density for both Tama and Catlin silt loam soils. Fig. 1 and 2 show the impact of different tillage practices on bulk density of Tama and Catlin soils, at three different soil depths, respectively. Lower bulk densities were generally observed for conventional tillage system as compared to the other tillage practices for both years and on both soils. However, no particular trend in bulk density between tillage systems of conventional, reduced and no-till practices was found. Statistical analysis using Duncan's multiple test procedure showed no significant impact of tillage on bulk density on a 5% probability level (Table 5). It was also hypothesized that bulk densities might be different for a tillage system with contour and up-and-down hill practices due to different hydrologic responses (lower runoff and higher infiltration for contour practice) for these two different practices. However, statistical mean comparison procedures did not reveal such differences. These finding are in close agreement with those obtained by Hill and

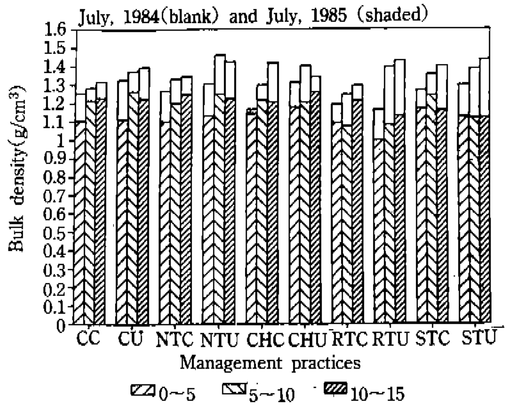

Fig. 1. Bulk density changes for Tama soil

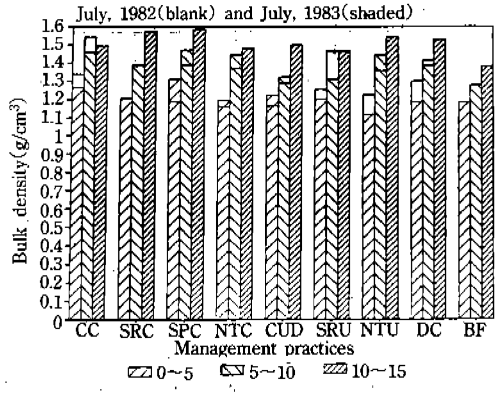

Fig. 2. Bulk density changes for Catlin soil

Table 5. Duncan s multiple range test results on Tama and Catlin silt soil with respect to effect of tillage, time of year, and depth on bulk density

(1) Tama silt loam soil

	0~5cm				5~10cm				10~15cm			
Tillage	84~6	84~7	85~6	85~7	84~6	84~7	85~6	85~7	84~6	84~7	85~6	85~7
CC	a,p,y	ab,q,x	ab,p,y	ab,p,y	a,p,x	ab,p,x	a,p,x	a,p,x	ab,pq,x	a,p,x	a,p,x	a,q,x
CHC	a,p,y	b,p,y	a,p,y	a,p,x	a,p,xy	ab,p,xy	a,p,xy	a,p,x	ab,p,x	a,p,x	ab,p,x	a,p,x
RTC	a,p,x	ab,p,x	ab,p,y	ab,p,xy	a,p,x	b,p,x	a,p,x	a,p,y	ab,p,x	a,p,x	a,p,x	a,p,x
STC	a,p,x	ab,p,x	a,p,x	a,p,x	a,pq,x	ab,p,x	ab,q,x	a,q,x	ab,pq,x	a,p,x	ab,q,x	a,q,x
NTC	a,pq,y	ab,p,x	ab,q,y	ab,q,y	a,p,x	ab,p,x	ab,q,y	a,pq,x	ab,p,x	a,p,x	ab,p,x	a,p,x
CU	a,q,y	a,p,x	ab,p,x	ab,q,x	a,p,x	ab,p,x	ab,p,x	a,p,x	ab,p,x	a,p,x	ab,p,x	a,p,x
CHU	a,q,y	ab,p,x	ab,p,x	a,pq,x	a,q,y	ab,p,x	ab,q,x	a,q,x	a,p,x	a,p,x	ab,p,x	a,p,x
RTU	a,p,x	ab,p,y	ab,p,y	b,p,x	a,q,x	ab,p,x	ab,pq,x	a,q,x	b,qr,x	a,p,x	a,pq,x	a,r,x
STU	a,q,z	ab,p,x	ab,q,x	a,pq,x	a,q,y	ab,p,x	b,r,x	a,qr,x	ab,p,x	a,p,x	a,q,x	a,q,x
NTU	a,pq,y	ab,p,x	b,r,y	a,pq,x	a,pq,x	a,p,x	ab,q,xy	a,q,x	ab,pq,x	a,p,x	ab,pq,x	a,q,x

(2) Catlin silt loam soil

	0~5cm				5~10cm				10~15cm			
Tillage	82~6	82~7	83~6	83~7	82~6	82~7	83~6	83~7	82~6	82~7	83~6	83~7
CC	bc,y	–	ab,y	a,y	bc,x	–	b,y	a,x	a,x	–	ab,x	ab,x
SSRC	bc,y	–	ab,y	a,y	bc,x	–	a,x	a,xy	a,x	–	a,x	a,x
SPC	ab,y	–	ab,y	a,y	c,xy	–	ab,y	a,x	a,x	–	ab,x	a,x
DIC	abc,-	–	ab,-	a,-	ab,-	–	ab,-	a,	a,-	–	ab,-	ab,-
NTC	ac,y	–	ab,y	a,y	abc,x	–	a,x	a,x	a,x	–	a,x	ab,x
CU	c,y	–	b,-	a,-	abc,x	–	b,-	a,-	a,x	–	ab,-	ab,-
SSRU	a,-	–	ab,-	a,-	ab,-	–	ab,-	a,-	a,-	–	b,-	ab,-
NTU	abc,y	–	a,-	a,-	a,x	–	a,-	a,-	a,x	–	a,-	a,-

*Footnote 1

DC : Cenventional contour

CHC: Chisel contour

RTC: Ridge-till contour

STC: Strip-till contour

NTC: No-till contour

CU : Conventional up-and-down hill

CHU: Chisel up-and-down hill

BF : Bare fallow

RTU: Ridge-till up-and-down hill

STU : Strip-till up-and-down hill

NTU: No-till up-and-down hill

SSRC : Sub-soil ridge contour

SPC : Sweep plow contour

DIC : Disk contour

SSRU : Sub-soil ridge up-and-down hill

**Footnote 2

1. The same letter means that the means are not significantly different from each other at a confidence level of 5%.
2. a, b, and c were used to compare means with respect to tillage practices.
3. p, q, and r were used to compare means with respect to seasons.
4. x, y, and z were used to compare means with respect to deptns.
5. "-" means that data were not available or too small to compare.

Cruse[6].

It was evident that bulk densities were increased with increases in depth although bulk densities between respective layers were not significantly different in general(Figs. 1~4, and Table 5). Differences in bulk density between the first and second layers were much higher than those between the second and third layers and were usually significant on a 5% probability level (Table 5). However, the differences between the second and third layers were not significant in general although some bulk density increases in the third layer were observed. It means that soil compaction mostly took place in the first layer. This reflects the impact of rainfall impact, crusting and sealing on the runoff and infiltration characteriatics.

Cropping sequence may also affect soil physical properties including bulk density. For example, cropping sequence of corn(1983), soybean(1984) and corn(1985) on Tama soil resulted in slightly higher bulk densities for 1984 as compared to 1985 values. Although we related the lower bulk densities in 1985 to climatic conditions but cropping sequence may also have played a role. However, no distinct trend was observed on Catlin silt loam soil regrading the effect of cropping sequence(Fig. 4). This may not be totally true for other cropping sequences. For example, literature indicates that grass roots pulverizes the soil profile due to biological loosening effect and may cause decreases in bulk density.

Winter cover with wheat seemed to have an influence on stabilizing soil texture during the winter and early spring by providing soil with frost protection and stabilizing soil matrix due to biological loosening effect of the dense root system in Tama silt loam soil(Fig. 5). Without winter cover strip-till practice showed a large changes in bulk density between layers both in June and July, 1984. However, changes in bulk density between layers were the least both in June and July, 1985 due to the impact of winter cover. The trend was

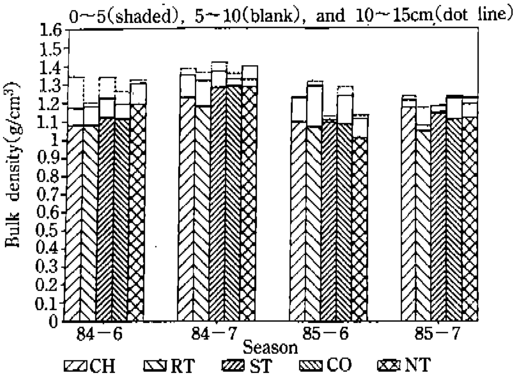

Fig. 3. Bulk density changes for Tama soil

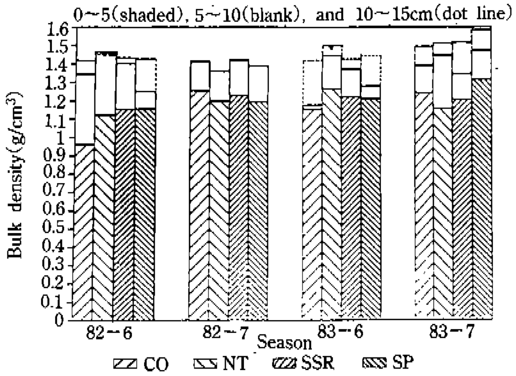

Fig. 4. Bulk density changes for Catlin soil

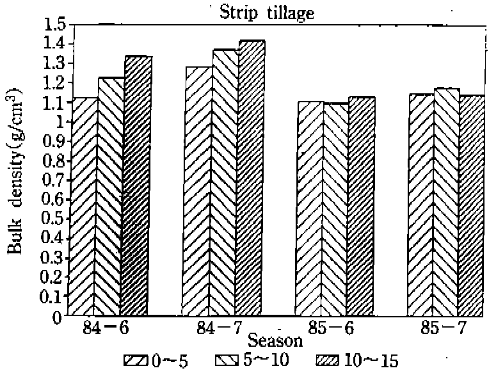

Fig. 5. Bulk density changes for Tama soil

the same for both contour and up-and-down hill practices.

Bulk densities in July were generally higher than those in June for both Tama and Catlin soils (Figs. 3 and 4). Bulk density differences between the first (0~5cm) and second(5~10cm) layer, and the second and third (10~15cm) layer in July were smaller than those in June except for very dry conditions of June and July, 1985. This may be due to the fact that tillage and seed-bed operations caused the soil to be loosened in June but natural compaction due to rainfall, consolidation due to infitration, wash-in of fine particles into bigger pores and so on made the soil to be more dense in July and resulted in higher bulk densities. However, these natural compaction processes seemed not to be effective during very dry season. For example, degrees of seturation (DSs) under different tillage practices in 1985(dry year) for Tama soil were much less than those in 1984 which was a wet year (Fig. 6). DSs in July, 1985 were even less than those in June of the same year. This explains that soil moisture contents decreased from seeding in June to July right before the rainfall simulation due to the lack of natural rainfall in 1985. Therefore, soil was not subject to natural compaction and bulk densities remained unchanged for that period.

Bulk densities under different tillage practices in Tama soil were also compared with respect to two different years. i.e., between July, 1984 and July, 1985, respectively(Figs. 1 and 2). Data indicated that bulk densities were lower in July, 1985 than in July, 1984 in all three soil depths, respectively. Considering that tillage practices were similar in both years, hydrologic conditions may have been the major factor for this trend. In other words, drier conditions in 1985 reduced the compaction and consolidation effects and resulted in low bulk densities. Therefore, climatic conditions play a major role in determining the impact of different management practices on bulk density and their ultimate effect on water and solute transport.

2. Degree of saturation(DS)

Figs. 6~10 show the impact of tillage, depth, time of year, and antecedent moisture conditions on degrees of saturation(DS) for both Tama and Catlin silt loam soils. Figs. 6 and 7 represent the changes in DS with tillage, depth, time of year for before dry run and at the end of wet run, respectively, for Tama soil. Fig. 6 shows that initial

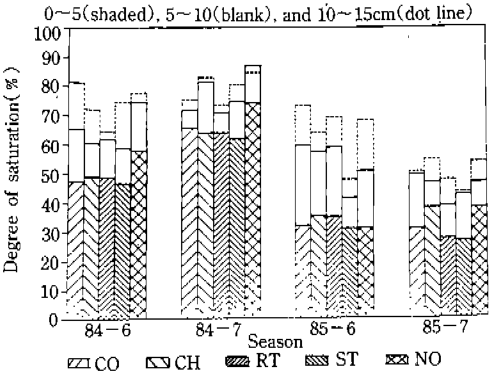

Fig. 6. Initial degree of saturation changes for Tama

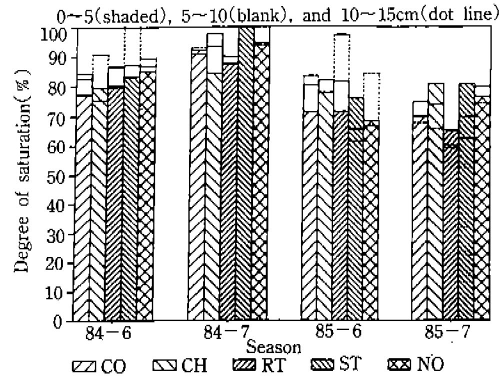

Fig. 7. Degree of saturation changes after wet run for Tama

DSs were lowest for strip tillage(ST) in 1984 and 1985. However, this trend did not hold after wet run(Fig. 7). Obviously for wet conditions(high soil moisture content) effect of tillage is somehow masked. Actually, the DS values under strip tillage were relatively higher for wet run conditions. Figs. 8~10 indicates that DS values were the lowest for before run conditions for Catlin soil on top 5cm of the soil. This trend did not hold true for the second(Fig. 9) and third(Fig. 10) layers. This again reflects the fact that top 5cm of soil is the most sensitive layer with respect to moisture changes.

DS was increased with depth. However, the increase rate seemed to depend on soil moisture conditions. If soil moisture content was relatively high, increase in DS with depth was small and no significant differences were encountered between layres and vice versa. For example, most of DSs observed in the first and second layers in 1985 (dry year) were significantly different while most of DSs observed in all theree layers in July, 1984 did not show significant differences(Fig. 6). Similar findings were true for Catlin soil(Figs. 8~10).

Initial degrees of saturation obtained for different tillage systems were significantly higher in 1984 (wet year) than in 1985 (dry year) for top 5cm of the soil profile(Fig. 6). The differences were obvious but not as significant for the second and third layers in of June, 1984 and in June, 1985, respectively. However, the differences obtained in DSs between July, 1984 and July, 1985 remained significant for all three layers.

Small pores are very improtant to describle nutrient loss or attenuation processes in the soil profile. They are also influential in holding or release of moisuture in the soil profile which may affect the degrees of saturation. For example, nitrifica-

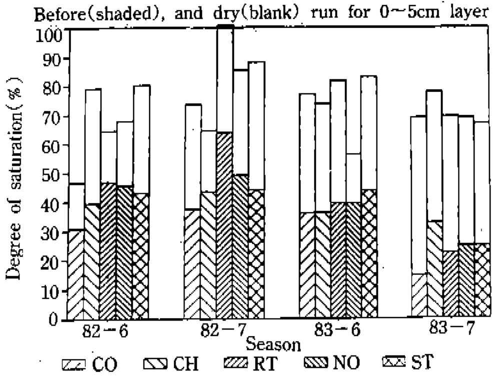

Fig. 8. Degree of saturation changes for Catlin

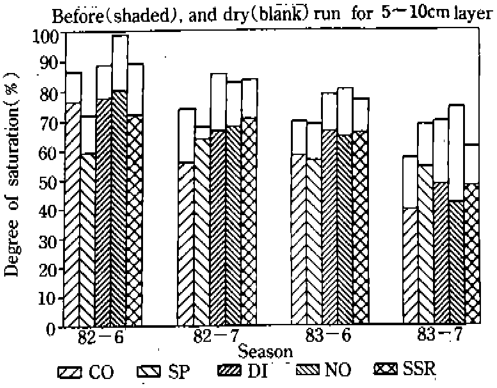

Fig. 9. Degree of saturation changes for Catlin

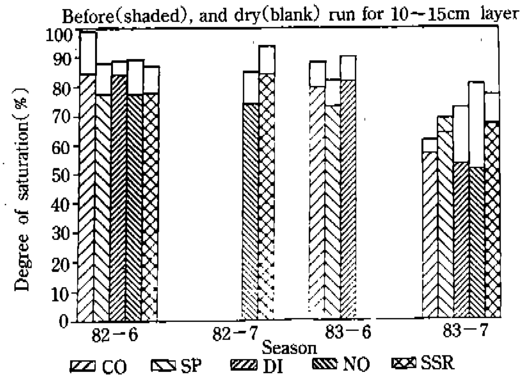

Fig. 10. Degree of saturation changes for Catlin

tion and denitrification reactions are largely dependent on soil's degree of saturation. Nitrate is produced by nitrifying bacteria (e.g., nitrosomonas) from ammonia along the macro pore area where infiltration water flows fast so that it provides dissolved oxygen to the area (aerobic zone). Denitrification takes place in the remote area from the macro pore flow where dissolved oxygen can not be supplied because of oxygen depletion by biological, chemical or biochemical activities. Nitrobacter and other living bacteria in the anaerobic zone are responsible for denitrification. If soil is completely dried, it will take some time for nitrobacter population to grow enough for denitrification to occur even after soil is saturated. Thereofore, it is necessary to keep a certain DS level in the soil in order to maintain proper nitrobacter population in the soil profile as an efficient nitrogen removal mechanism. This relationship is needed to describe nitrogen loss from the agricultral fields or nitrogen removal mechanisms in the intervening land zones.

DS at the end of very wet run, reached to 90% and 80% for normal and dry seasons, respectively. Drier initial conditions resulted in lower DSs at the end of very wet run. Data presented in this study suggest that the assumption of "complete saturation at the end of very wet run by many researchers" may be in error. Therefore, initial DS or initial moisture status before the first dry run should be considered for assessing complete saturation statues at the end of very wet run. This may impove determination of infiltration rate and other soil hydraulic properties.

IV. Conclusions

Through analysis of the results let to the following conclusions :

1. Tillage had no significant effect on bulk density and degree of saturation for both Tama and Catlin silt loam soils. However, bulk densities measured under conventional system were the lowest as compared to the other tillage systems. Higher degree of saturation was maintained under sweep plow and both chisel and no-till for Catlin and Tama soils, respectively.
2. Bulk density and degree of saturation increased with increases in depth for both Tama and Caltlin soils.
3. Winter cover seemed to stabilize the soil matrix to reduce the bulk density differences between the layers.
4. The bulk density values between wet year (July, 1984) and dry year(July, 1985) showed clear distinctions in all of the three layers.
5. Low initial degree of saturation (25~35%) resulted in low degree of saturatioin at the end of very wet run by about 10~20% compared to that of higher initial degree of saturation.

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