Studies on the Runoff and Soil Loss from Small Agricultural Watersheds with different treatments near Lincoln, Nebraska

處理를 달리한 小農業流域의 流出과 土壤流失에 關한 研究

——네브라스카州 링컨地方을 中心으로——

李　淳　赫*
Soon Hyuk Lee, Howard D. Wittmuss**, Jose da Silva Madeira Netto**

摘　要

本研究는 3個의 서로 다른 農地保全處理를 가진 試驗區 및 테라스處理가 없는 牧草用 Bromegrass 試驗區에 있어서의 降雨, 流出現象과 土壤流失 關係를 究明함으로써 合理的인 農地保全 對策과 作付體系를 提示코저 하는데 그 目的이 있다. 降雨, 流出 및 土壤流失에 關한 分析考察은 3個의 農地保全 試驗區에서는 5年間(1972—1976年)의 資料를 그리고 Bromegrass 牧草試驗區에서는 3年間(1972-1974年)의 資料를 對象으로 하였다. 3個의 農地保全處理區는 첫째로Non-terrace에 秋耕 春條播形式의 慣行法에 依한 非處理區와 둘째로 急逆勾配 테라스를 가진 草生水路에 가을 收穫時 crop residue를 남겨두고 봄에 耕作條播하는 Till plant system을 가진 草生水路區 그리고 마지막으로 地下排水와 함께 逆勾配 Terrace를 具備한 條播의 Till plant system을 採用한 排水區로 나누어진다. Bromegrass 處理區는 Terrace나 其他 農地保全策이 없는 牧草用 試驗區 이다. 以上의 研究에서 얻어진 結果를 要約하면 다음과 같다.

1. 試驗期間內의 平均降水量은 네브라스카 링컨 地方의 76年間의 平均值, 728mm보다 66mm가 적은 662mm이였고 1974年과 1975年은 平均值 보다 300mm나 적은 極히 乾燥한 해 이였으며 1972年과 1976年은 거의 平均降水量에 가까웠고 1973年만은 平均值보다 240mm나 더 많은 多雨年 이었다.
2. 慣行의 作付體系를 가진 非處理區에서의 年平均 流出高(2.44cm)는 逆勾配의 Terrace를 가지고 Till-plant system을 採擇한 草生水路區의 流出高(2.42cm)와 거의 類似한 値였다.
3. 排水處理區로부터의 流出은 3個의 農地保全 處理區 中에서 5年間의 平均值가 1.57cm/year로 草生水路區와 非處理區의 流出보다 35%나 적은 가장 낮은 結果를 나타내었다.
4. Bromegrass 牧草處理區에서의 流出은 放牧程度에 따라서 影響되었다. 1972年의 無放畜時 流出은 다른 3個 處理區로 부터의 流出의 7 乃至 19% 內인 0.07cm 程度였으나 1973年과 1974年의 放畜年에는 條播의 3個 處理區(3.4~5.18cm)에 필적되는 年平均 4.61cm로 나타났다.
5. 全體 試驗區로부터의 年平均 土壤流失量은 Sharpsburg 粘質壤土에 對한 S.C.S. 限界許容值 10ton/ha/year 以內로 나타났다.
   非處理區에서의 土壤流失量은 平均 2.56ton/ha/year로 높게 나타난 反面 3個의 서로 다른 處理區인 排水區, 草生水路區 및 Bromegrass區에서는 各各 0.152, 0.192 및 0.290ton/ha/year로 낮은 結果를 가져왔다.
6. 平均 沈澱量에 對한 L.S.D. 檢定 結果 全試驗區中 非處理區가 高度의 有意差를 나타낸 反面 排水區, 草生水路區 및 Bromegrass 牧草區 間에는 아무런 有意差가 認定되지 않았다.
7. 農地保全 處理區인 排水區와 草生水路區는 非處理區에 比해 낮은 尖頭 流出量과 낮은 土壤流失量을 나타내었다.

* 忠北大學校 農科大學
** Dept. of Agri. Engineering, University of Nebraska, U.S.A.

Ⅰ. Introduction

We normally think that the main problem associated with erosion is the runoff. Erosion is the loosening or dissolving and removal of soil and rock material from their environment by wind, water or Ice.

Rainfall and runoff possess detachment and trasportation capabilities. The factors that affect raindrop erosion are the drop velocity, drop diameter, rainfall intensity and soil characteristics.

Erosion and sedimentation by water include the processes of detachment, transportation and deposition of soil particles. The required energy to develop those processes are provided by falling raindrops and water moving on the soil surface.

The costs of erosion and sedimentation to society by runoff is very high. Piemental, et al[7] cites estimates that the loss in crop productivity resulting from wind and water erosion costs annually $ 800 million and that the annual cost of sediment damages to water resources in the United States are estimated at $ 500 million. The loss of the top soil in severely eroded lands reduces soil fertility causing a decrease in productivity or an increase in costs of production.

For the erosion control, we mainly rely on four means: vegetation, plant residue, improved tillage methods and residual effect of crops in rotation. Especially, The till-planting system was developed as a system to reduce wind and water erosion by leaving crop residue on the soil surface. Other advantages of the system include improved environmental conditions for seed germination and plant development. And terraces are conservation structures which can control soil and water movement on the field by reducing the slope length to smaller segments, thus reducing sheet and rill erosion, preventing the formation of gullies and retaining runoff. Therefore, This study was established to determine the effect of different conservation systems and tillage practices on water and soil loss from four agricultural watersheds. The four watedsersh treatments include Bro-megrass watershed, Non-conservation, Grassed waterway and Tile outlet watershed.

Ⅱ. Experimental procedure

1) watersheds description

We had experiment with four different treatments at two dif erent locations in Eastern Nebraska. Three of the watersheds were located in the Rogers farm, an experimental farm of the University of Nebraska for soil and water conservation studies located 8 miles east of Lincoln. The fourth watershed was located in a private farm located 6 miles north of Lincoln. The soil of the watersheds classified as sharpsburg silty clay loam. This soil has a dark-colored, friable surface layer 20 to 30 cm deep. Both surface and internal drainage are good. All the essential plant nutrients are present in this soil. Range of area for the watersheds is 4.6 ha to 15.1ha and the average for all watersheds is 6%.

The four watersheds have some different treatments as follows:

(1) Tile outlet watershed
Steep backslope terraces with underground waterway using till-planting on the contour.

(2) Grassed waterway watershed
Steep backslope terraces with grassed waterways and row cropped using till-planting on the contour

(3) Bromegrass watershed
Bromegrass pastures without terraces

(4) Non-conservation watershed
Row cropped using conventional tunr plow tillage with rows running parallel to field borders and non-terraced.

2) Management Practices

The watersheds in the Rogers Memorial Farm were planted to row crops during the period of study (1972-1976). One of the watersheds, non conservation watershed was a 4.9 ha field planted using conventional tillage methods. This conventional tillage system consisted basically of cutting stalks and moldboard plowing in the fall, and disking twice before surface planting in the spring. The rows were oriented parallel to the field boarders and no terraces or other conservation practices were installed. The cropping rotation used during the period of study was corn, corn, soybeans, milo and soybeans. The two other watersheds, tile outlet and grassed waterway were continuously planted to corn using the till-plant system.

In this system, the crop residue was left standing on the ground after the corn was harvested in the fall. In the spring the stalks were cut and the field disked or sweep plowed once and planted with a Buffalo till-planter.

Tile outlet watershed in this study was a 15.1 ha field with parallel steep backslope, impondment type terraces with underground tile outlet, spaced 58 and 43 meters apart.

Grassed waterway watershed consisted of a 6.5 ha field protected with parallel steep backslope terraces spaced 58 and 43 meters apart with variable channel grade which disposed the runoff into a grassed waterway.

Bromegrass watershed,a 4.6 ha field which was belong to the private farm was kept ungrazed in 1972, and the grass was very tall during the growing season. In 1973 and 1974 cattle had access to this watershed and he bromegrass was heavily grazed. At the end of the fall 1974, the studies at this watershed were discontinued.

The row crop watersheds were fertilized with annhydrous ammonia at the rate of 224 kg/ha/year of N. All the fertilizer was applied at once in the spring. No fertilizer was applied on the Bromegrass watershed.

3) Hydrologic measurements

(1) Measurements of rainfall and runoff

A raingage and three foot H flumes were installed at the outlet of each watershed. water stage recorders of stevens type A with rainfall accessory continuosly recorded the runoff and rainfall on the the same chart.

The runoff stage recorder was operated by means of a float located inside a stilling well connected to the flume. The rise and fall of the float moved a marking stylus laterally across a chart. The raingage recorder was driven by a float located inside a chamber which received the rain collected by the rain gage funnel. The chart advance was controlled by a weight driven clock.

Table-1. Watersheds description

Watershed	Area (ha)	Slope (%)	crop (year)	Rotation (crop)	Conservation Practice
Tile Outlet	15.1	4-8	1972 1973 1974 1975 1976	Corn Corn Corn Corn Corn	Parallel Terraces with Tile outlet Till-Planting on contour
Grassed Waterway	6.5	4-8	1972 1973 1974 1975 1976	Corn Corn Corn Corn Corn	Parallel Terraces with Grassed waterway Till-Planting on contour
Non-conservation	4.9	4-8	1972 1973 1974 1975 1976	Corn Corn Soybean Milo Soybean	Conventional Tillage No Mechanical Protection
Bromegrass	4.6	4-8	1972 1973 1974	Bromegrass Bromegrass Bromegrass	No Mechanical Protection

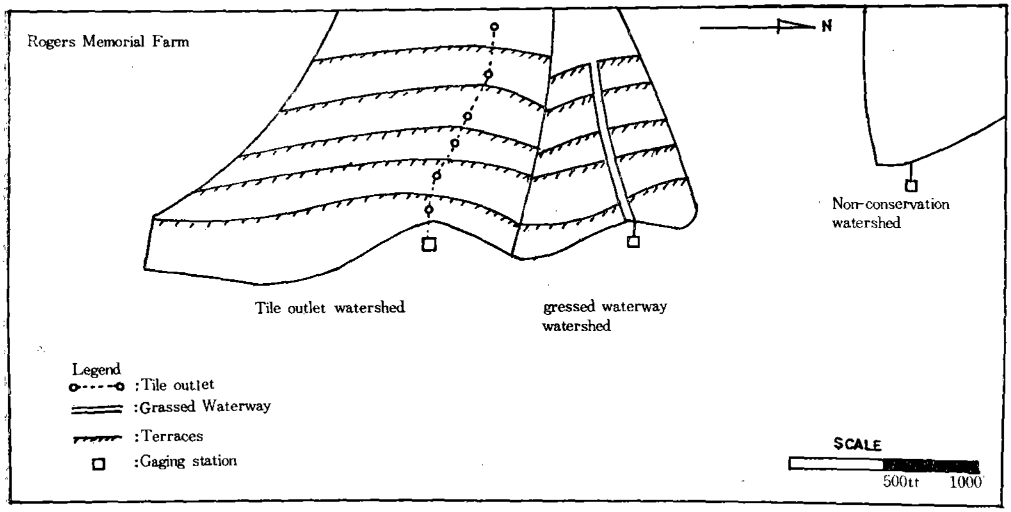


Fig. 1. Tile outlet, Grassed waterway and Non-conservation watersheds, located near Lincoln, Nebraska

(2) Runoff samplers

An automated runoff sampler located downstream from the flume collected samples for sediment determination. The runoff sampler was an automated device, which consists of a rotating arm moved by an electric motor powered by a 12 V battery. This electric motor was turned on and off by a mercury switch connected to a float placed inside the stilling well. When runoff started and the water level rose, the system turned on and when runoff ceased it turned off.

During a runoff event, aliquots were taken at every 15 minutes interval and placed into a 20 gallon plastic containers. At the end of each storm, the water sample was used for sediment yield determination.

Picture I shows a general view of one of the gaging stations, and Picture 2 shows the Stevens type A recorder.

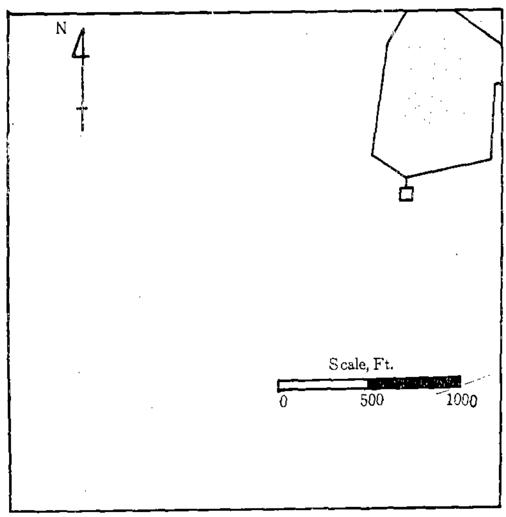


Fig. 2. Bromegrass watershed located near Lincoln, Nebraska.

4) Volume of Runoff and Sediment determination

The runoff stage graph from the runoff recorder was used to obtain the corresponding rates of discharge. The conversion of water depth in the H flume into rates of discharge was done using a calibration table for the 3 foot H flume shown in Table-2.

The volume of discharge for individual storm events was calculated using the trapezoidal rule of integration. For improved accuracy, time increments were usually 15 minutes or less.

The discharge, in cm for each time increment, was calculated as follows:

Table-2. Flow discharge through 3.0 foot H-flume in $M^3/S \times 10^{-3}$ (from International Institute for Land Reclamations and Improvement)

ha (m)	0	2	4	6	8
0.00					
0.01					
0.02				0.763	0.858
0.03	0.959	1.06	1.18	1.29	1.41
0.04	1.54	1.67	1.81	1.95	2.09
0.05	2.25	2.40	2.57	2.74	2.91
0.06	3.09	3.27	3.46	3.66	3.86
0.07	4.06	4.28	4.49	4.72	4.95
0.08	5.18	5.42	5.66	5.92	6.17
0.09	6.43	6.70	6.98	7.26	7.54
0.10	7.83	8.13	8.44	8.75	9.06
0.11	9.38	9.71	10.0	10.4	10.7
0.12	11.1	11.4	11.8	12.2	12.5
0.13	12.9	13.3	13.7	14.1	14.5
0.14	14.9	15.4	15.8	16.2	16.7
0.15	17.1	17.6	18.0	18.5	19.0
0.16	19.4	19.9	20.4	20.9	21.4
0.17	21.9	22.4	23.0	23.5	24.0
0.18	24.6	25.1	25.7	26.3	26.8
0.19	27.4	28.0	28.6	29.2	2.98
0.20	30.4	31.1	31.7	32.3	33.0
0.21	33.6	34.3	35.0	35.6	36.3
0.22	37.0	37.7	38.4	39.1	39.8
0.23	40.5	41.3	42.0	42.8	43.5
0.24	44.3	45.1	45.8	46.6	47.4
0.25	48.2	49.0	49.8	50.7	51.5
0.26	52.3	53.2	54.0	54.9	55.8
0.27	56.6	57.5	58.4	59.3	60.2
0.28	61.2	62.1	63.0	64.0	64.9
0.29	65.9	66.8	67.8	68.8	69.8
0.30	70.8	71.8	72.8	73.8	74.9
0.31	75.9	77.8	78.0	79.1	80.2
0.32	81.2	82.8	83.4	84.5	85.7
0.33	86.8	87.9	89.1	90.2	91.4
0.34	92.5	93.7	94.9	96.1	97.3
0.35	98.5	99.7	101	102	103
0.36	105	106	107	109	110
0.37	111	112	114	115	116
0.38	118	119	120	122	123
0.39	125	126	127	129	130
0.40	132	133	135	136	138
0.41	139	141	142	144	145
0.42	147	148	150	151	153
0.43	154	156	158	159	161
0.44	163	164	166	167	109
0.45	171	173	174	176	178
0.46	179	181	183	185	186
0.47	188	190	192	194	195
0.48	197	199	201	203	205
0.49	207	208	210	212	214
0.50	216	218	220	222	224
0.51	226	228	230	232	234
0.52	236	238	240	242	244
0.53	246	248	251	253	255
0.54	257	259	261	263	266
0.55	268	270	272	274	277
0.56	279	281	283	286	288
0.57	290	293	295	297	300
0.58	302	304	307	309	312
0.59	314	317	319	321	324
0.60	326	329	331	334	336
0.61	339	341	344	347	349
0.62	352	354	357	360	362
0.63	365	363	370	373	376
0.64	378	381	384	387	389
0.65	392	395	398	400	403
0.66	406	409	412	415	418
0.67	420	423	426	429	432
0.68	435	438	441	444	447
0.6?	450	453	456	459	462
0.70	465	468	471	475	478
0.71	481	484	487	490	494
0.72	497	500	503	506	510
0.73	513	516	519	523	526
0.74	529	533	536	539	543
0.73	546	550	553	556	560
0.76	563	567	570	574	577
0.77	581	584	538	592	595
0.78	599	602	606	610	613
0.79	617	620	624	628	632
0.80	635	639	643	647	650
0.81	654	658	662	666	669
0.82	673	677	631	685	689
0.83	693	697	701	705	709
0.84	713	717	721	725	729
0.85	733	737	741	745	749
0.86	753	757	762	766	770
0.87	774	778	783	787	791
0.88	795	800	804	808	813
0.89	817	821	826	830	835
0.90	839	843	848	852	857

$$D_{ti+1-ti}(cm) = \frac{R_{ti}+R_{ti+1}}{2} \times \frac{t_{i+1-ti}(min) \times 60(sec.x\ min.) \times 100(cm/m)}{A(ha) \times 10^4(m^2/ha)}$$

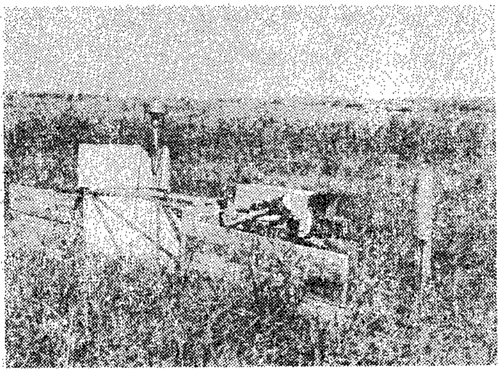
where

$D_{ti+1-ti}$ = Depth of runoff discharge at a time increment t_{i+1-ti}, in cm

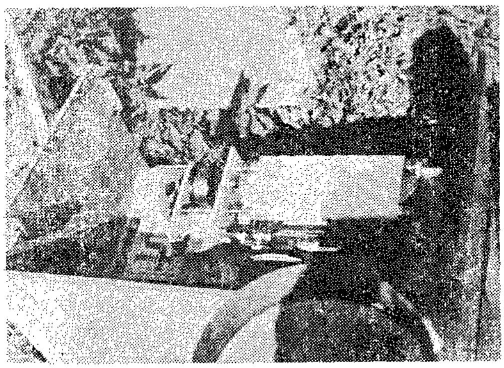
R_{ti+1} and R_{ti} = Rates of discharge at times t_{i+1} and ti, in m^3/sec

t_i and t_{i+1} = Two consecutive times measured from the beginning of the runoff event, in minutes

A = Watershed Area in ha.



Picture 1. General view of a gaging station at Rogers Memorial Farm.



Picture 2. The stevens Type A recorder.

The total discharge for a runoff event was the summation of the discharge of all time increments as follows:

$$D=\sum_{i=1}^{n} D_{ti+1-ti}$$

where D=Total runoff discharge in cm.

Finally, the volume of runoff in ha-cm was obtained by multiplying the depth of runoff by the watershed area:

$V(ha \cdot m)=D \times A$

where V=volume of runoff in ha·cm

D=depth of runoff in cm

A=watershed area in ha

For the sediment determination, sediment content of the samples were determined by the soil laboratory of the Agricultural Engineering Department. The following procedure was used:

1) the 20 gallon container with the sampled material (runoff water and sediment) was weighed on standard platform type scale (Wt)

2) A weighed amount of powdered alum (Wa) was added to the suspension to accelerate the settling of the sediment.

3) After all the sediment was settled, the water was siphoned off.

The remaineder was transferred to a beaker of known tare weight, and the tare weight of the 20 gallon container (Wc) obtained.

4) The sediment was oven dried at 105°C and weighed (Ws)

5) The sediment concentration in percentage was obtained as follows:

$$\%\ \text{sediment}=\frac{(Ws-Wa)\times 100}{(Wt-Wc)-(Ws-Wa)}$$

where

% sediment=concentriaton of sediment in runoff water in percentage.

Ws=Weight of oven dried sediment plus alum in grams

Wa=weight of alum in grams

Wt=weight of sediment plus water plus sample container in grams

Wc=Weight of 20 gallon container in grams

The amount of sediment yield for each runoff event was obtained as follows:

sediment yield(kg/ha)

$$=\frac{V(ha\cdot cm)\times \rho w(gm/cm^3)\times \%\ \text{sediment}}{A(ha)\times 10^{-8}ha/cm^2\times 100}\times 10^{-3}(kg/gm)$$

where

V=volume of runoff in ha·cm

ρw=density of water in gm/cm^3

A=watershed Area in ha

5) Statistical Analysis

Convariance analysis was used to test difference of means of the runoff and sediment yield among the four watersheds. The covariance type of analysis was used because the precipitation that generated runoff was not equal at all watersheds. With this analysis procedure, the parameters being tested are first adjusted to a common precipition value and then the adjusted means are tested using the F test procedure for unequal number of observations

The four watersheds were considered as experimental units. Since no replication of the experimental units were available, the treatment effect could not be isolated from the effect of the natural differences among water sheds. However, since the watersheds characteristics are almost the same, a careful interpretation of the results of the statistical analysis may make possible some inferences about the differences and similarities of the effect of the treatments tested on the variables of interest. For the statistical analysis, the 5 year data, for the row cropped watersheds, and 3 year data, for the Bromegrass watershed, were lumped in four sets of data, thus no differences among years were tested.

The statistical analysis were performed using the SAS(Statistical Analysis System) at the Biometric Center of the University of Nebraska. When the covariance analysis indicated significant differences among treatment means, the least significant difference method was used to distinguish the watersheds with significant difference means.[12]

Ⅲ. Results and Discussion

1) Precipitation

preciptation is one of the many factors affecting runoff, soil loss. Precipitation was recorded at each research site during each growing season period. During the winter (approximately November 15 to March 1), no records of rainfall or runoff were taken. For the periods not monitored, precipitation data were taken from the WSO station for Lincoln Nebraska, which is located 8 miles or less from the watersheds. The period of record of each year, amounts of rainfall recorded and annunal precipitation at each of the watersheds are presented in Table-3.

More than 92.5, 81.2, 83.2, 60.9, and 83.7 percent of the annual precipitatioon were recorded at the sites from 1972 through 1976 respectively. Annual precipitation during the course of the experiment, was quite variable, ranging from about 380mm in 1974 to as much as 1010 mm in 1973.

The five year mean precipitation over the four watersheds was 662.3mm, which is 66.0 mm below the 76 year average, 728.3mm annual rainfall for Lincoln, Nebraska. For the period 1972-1974 annual precipitation at the bromegrass watershed varied from 382mm to 943mm for an average of 715mm (Table-4)

To compare the annual precipitation exper-rienced during the period of record with that experienced over a long period of record with that experienced over a long period of years, a class frequency analysis of the 76 years rainfall data for Lincoln was determined, using the Weibull formul[13].

Twelve precipitation classes of 63.5mm of range were considered. The probability of exceedence of those precipitation classes were claculated and on a normal probability paper (Fig. 3)

The probability of occurrence of annual precipitation equal or greater to those observed in 1972 through 1976 was respectively 53.5, 10.5, 97.7, 95.5 and 47.5 percent. These values suggest that 1974 and 1975 were very dry years, 1973 very wet, and 1972 and 1976 were about average years according to the precipitation patterns for Lincoln.(Table-4)

In fact, 1973 average precipitation over the four watersheds exceeded the 76 year average by 240mm, while 1974 and 1975 precipitation was respectively 333mm and 284 mm below the average. In 1972 and 1976, precipitation exceeded the average by only 9.7 mm and 35.4 mm, respectively. The distribution of precipitation within the year is also important for runoff and erosion studies. Rainfall, in periods when the soils have good vegetation cover, is expected to have less impact on runoff and soil erosion than when the soil is loose and smooth due to tillage operations, and unprotected by the crop canopy. The average monthly distribution of precipitation for Lincoln follows approximately a gaussian curve, being small at the beginning of the year, increasing to a maximum of 10.59 cm n June and decreasing again to 2.2 cm im December during the periods of study. This distribution pattern indicates that the erosion potential for the Lincoln area is high since the period of greatest amount of precipitation coincide with the time more favorable for the erosion hazards.

2) Runoff

During the period 1972-1976, 36, 49, and 24 runoff events occurred in the Tile outlet,

Table-3. Annual recorded and total precipitation for four watersheds near Lincoln, Nebraska for 1972-1976

Year	Period of Record	Watershed	Precipitation recorded (mm)	Total precipitation (mm)
1972	March 15-November 20	Tile Outlet	671.6	723.6
		Grassed Waterway	647.6	700.1
		Non-conservation	654.0	706.5
		Bromegrass	771.2	821.2
1973	March 9-October 12	Tile Outlet	757.4	918.5
		Grassed Waterway	844.0	1005.1
		Non-Conservation	869.5	1010.6
		Bromegrass	765.6	942.8
1974	March 4-November 1	Tile Outlet	326.7	338.0
		Grassed Waterway	341.5	410.2
		Non-Conservation	339.4	400.7
		Bromegrass	321.1	382.4
1975	March 25-November 14	Tile Outlet	256.6	421.6
		Grassed waterway	292.5	457.5
		Non-Conservation	290.1	455.1
		Bromegrass*	—	—
1976	April 14-November 1	Tile Outlet	621.4	742.4
		Grassed Waterway	664.7	785.7
		Non-Conservation	641.9	762.9
		Bromegrass*	—	—

*Plots discontinued

Table-4. Annual rainfall and ruoff for four watersheds near Lincoln, Nebraska

Watershed \ Rainfall&Runoff \ Year	1972		1973		1974		1975		1976		Average	
	Rain-fall (mm)	Run-off (cm)	Rain-fall (mm)	Run-off (cm)	Rain-fall (mm)	Run-off (cm)	Rain-fall (mm)	Run-off (cm)	Rain-fall (mm)	Run-off (cm)	Rain-fall (mm)	Run-off (cm)
Tile Outlet	753.6	0.36	920.3	6.79	388.0	0.02	421.6	0.65	742.4	0.02	645.2	1.57
Grassed waterway	758.0	1.03	1005.1	9.18	410.2	0.06	457.5	0.46	785.7	0.03	683.3	2.42
Non-conservation	706.5	0.68	1010.6	10.36	400.7	0.01	455.1	1.07	762.9	0.13	667.2	2.44
Bromegrass	821.2	0.07	942.8	8.92	382.4	0.30	—	—	—	—	715.5*	3.02*

*Average of 3 years for Bromegrass watershed (1972-1974)

Grassed waterway and Non-conservation watersheds respectively. In the Bromegrass watershed, 15 runoff event occurred from 1972 to 1974. Average annual runoff for the period 1972-1976 was respectively 1.57, 2.42, and 2.44 cm/year for the Tile outlet, Grassed waterway and non-conservation watersheds. For the Bromegrass watershed, average annual runoff for the period 1972-1974 was 3.02 cm/year.

Annual runoff was quite variable among the years ranging from 0.02 cm to 6.79 cm for the tile outlet watershed, 0.03 cm to 9.18 cm for the Grassed waterway watershed from 0.01cm to 10.36cm for the Non-conservation watershed and from 0.07 to 8.92cm for the Bromegrass watershed. (Table-4)

Runoff recorded at the three row cropped watersheds totaled from 7.84 to 12.25cm during the five year period of study. The total runoff from the Bromegrass watershed for the period 1972-1974 was 9.29cm.

The relatively abundant and well-distributed precipitation of 1973 kept the soil moisture at high levels for long periods of the year.

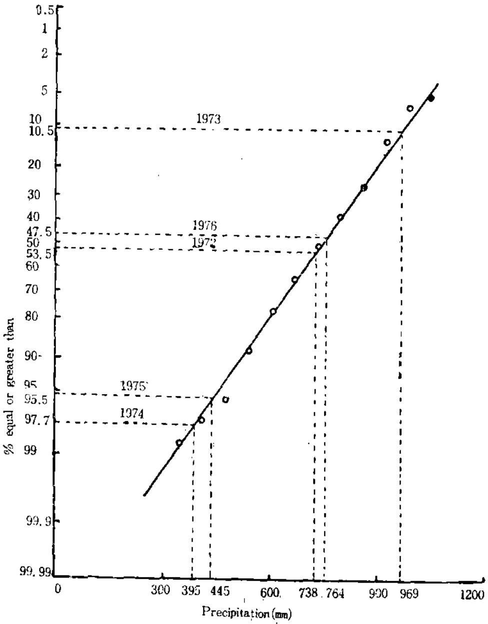


Fig. 3. Frequency analysis of the rainfall data for four watersheds near Lincoln, Nebraska (1972-1976)

Table-5. Analysis of covariance for runoff

Source	D.F.	S.S.	M.S.	F
Regression	4	23.3275	5.8319	11.8252**
Watershed	3	1.9792	0.6597	1.3377
Precipitation	1	21.3484	20.2389	41.0381**
Error	119	58.6876	0.4932	
Corrected Total	123	82.0151		

**Highly significant

Consequently, the infiltration capacity of the soil was reduced, that resulted in a greater number of runoff events and high volume of runoff as compared with the other four years. Between 46 and 58 percent of the total numaer of runoff events from the three row corp watersheds and 87 percent of the runoff events from the Bromegrass watershed occured in 1973. The runoff for 1973 contributed to more than 85 percent of the total runoff volume measured during the entire experimental period.

For the other four years of the experiment the runoff discharges from all the watersheds were relatively low, and nevar exceeded 1.1 cm in any of the years (Table-4). For the five years the Grassed waterway watershed and the Non-conservation watershed averaged about equal amounts of runoff(2.42 and 2.44cm respectively) and Tile outlet about 35 percent less than both (1.57cm). These results show that for conditions that prevailed in 1972-1976, the graded channel terraces and the till-plant system of the Grassed waterway watershed failed in reducing runoff as compared with the turnplow tillage system in the Non-conservation watershed. However, total runoff losses were low, no heavy runoff producing storms occurred, especially in the spring months and most rainstorms ceased before runoff appeared at the gaging stations. Sharp, et al[9] and Richardson[8] reported that drainage type terraces alone may not reduce surface runoff water, and Bulter[2] showed that the effectiveness of the till-plant system depended strongly on the antecedent soil moisture conditions.

The results of this study agree with the conclusions of the authors referred to above. In 1973, when the soil remained wet almost all year, the differences in runoff volumes between the Non-conservation watershed and the Grassed watershed were very small.

In 1975, as a result of low precipitation in 1974 and 1975, the soil remained dry for long periods of time. Under these conditions, the effectiveness of the till-plant system in reducing runoff as compared with the turn plow system was very evident. Runoff from the Grassed waterway and Non-conservation watersheds were respectively 0.4 cm and 1.07 cm for 1975.

Laflen, et al[5] explains that the till-plant system increases infiltration because of an unconsolidated mixture of soil and sediment residue which is deposited upon the original untilled soil surface, and also increase surface storage availability.

Runoff from the tile outlet watershed was the lowest of the three row cropped watersheds, averaging for the period 1972-1976, 1.57cm/year (Table-4) which is about 35 percent less than the runoff from the Grassed water way and Non-conservation watersheds. Since both, Tile outlet and Grassed waterway watersheds had the same tillage treatment, the differences in runoff between them may be associated to the impondment in the terraces. In the Tile outlet terraces, runoff water from the area between two consecutive terraces is ponded temporarily in low-lying areas around the risers which dispose the water to underground conduits. During the time the water is ponded, part of it infiltrated and percolated, which caused the volume of surface runoff to be reduced.

Runoff from the Bromegrass watershed presented two different trends during the three years of monitoring. In 1972, the volume of runoff from the Bromegrass watershed was the lowest, totaling only 0. 07 cm as compared with 0. 36, 1. 03cm and 0. 68cm, respectively from the tile outlet, Grassed waterway and Non-conservation watersheds(Table-4).

In 1973 and 1974, the number and volumes of runoff were comparable to those from the Non-conservation watershed. Those differences in both periods may ae explained by the intensity of grazing that prevailed in those years.

In 1972, the bromegrass was kept ungrazed all year. consequently a dense vegetation developed, providing a good cover to the soil. This dense canopy intercepted the rain drops, and som of the rain was evaporated before reaching the ground. smith, et al[10] reported interception percentages that ranged from 7 to 43 percent. Close growing vegetation, as is the case of the Bromegrass, has a very high consumptive use of water, which dries out the soil, resulting in a greater infiltration capacity.

During 1973 and 1974, however, the Bromegrass was heavily grazed during the entire growing season. The vegetative cover was severely reduced, and areas with bare soil exposed. Under those conditions, the effectiveness of Bromegrass in reducing runoff was very limited. In 1973 and 1974, runoff from the Bromegrass watershed totaled 8. 92 cm and 0. 30 cm respectively, compared with 10. 36 cm and 0. 01cm for the Nonconservation watershed for the same two-year period (Table-4)

An analysis of covariance for the runoff showed that no significant differences were found among the four different watersheds (Table-5).

The peak rates of runoff were also affected by the conservation treatments. Table-6 and Fig. 4 show the distribution of the total number of runoff events in peak rate classes. In both watersheds with the tillplant system, there was a great concentration of runoff events with very low peak rates. For the Bromegrass and Non-conservation watershed, a greater concentration of peak rates was observed in the higher peak classes. Also, the total number of runoff events from the Grassed waterway and Tile outlet watersheds were much greater (36 and 49, respectively) than from the Non-conservation watershed, may be attributed to the rougher conditions of the soil surface left by the moldboard plow during the spring, as compared with till-planting tillage. Those rougher conditions of the soil surface during the spring were enough to eliminate ruuoff from a number of rainstorms that caused low-volume, low-peak rates of runoff in the Tile outlet and Grassed waterway watershed.

The maximum peak rates of runoff for the Tile outlet, Grassed waterway, Non-conservation and Bromegrass watersheds were respectively 0. 14cm/hr, 1. 0cm/hr, 1. 58cm/hr and 0. 92cm/hr. These results and those presented at Table-6, show that all the conservation treatments were effective in reducing peak rates of runoff, as compared with the turn plow tillage, Non-terraced treatment. Even when the total volume of runoff was approximately equal for all the watersheds, the peak rates of runoff from the Tile outlet, Grassed waterway, and Bromegrass watersheds were less than that from the Non-conservation watershed.

The hydrographs of the October 11, 1973 storm are used to illustrate this fact(Fig. 5)

The rain that originated this runoff were 32. 8mm, 30. 5 mm, 33. 0mm and 31. 8mm at the Tile outlet, Grassed waterway, Non-conservation and Bromegrass watersheds, respectively. Runoff in the amouts of 1. 35cm, 1. 97 cm, 1. 82cm, and 1. 69cm and peak rates of 0. 14cm/hr, 1. 0cm/hr, 1. 58cm/hr and 0. 92 cm/hr occurred at the Tile outlet, Grassed waterway, Non-conservation and Bromegrass watersheds, respectively. These results show that peak rate from the watershed with graded channel terraces and till-plant system were about 73 percent of the peak rate from the Non-conservation watershed even though the volume of runoff from the former was slightly higher than from the latter.

The amounts and peak rates of runoff from the Bromegrass watershed were less than those from the Grassed waterway watershed, but the shape of the hydrographs were very similar. A possible reason for these differences may be the antecedent moisture conditions of the soils in both watersheds. The rainfall on October 9 and October 10 totaled, respectively, 108.6mm and 69.0mm at the grassed waterway and bromegrass watersheds.

The peak rate and volume of runoff for the storm of October 11, 1973, as indicated above, was significantly less from the Tile outlet watershed than from the others. The peak rates of runoff from The Tile outlet terraces are limited by an orifice plate placed inside the riser. The depth of the water stored in the ponded area and the size of the orifice determined the rates of discharge presented in the hydrograph.

Table-6. Distribution of the runoff events in peak rate classes

Reak rate classes (cm/hr)	Tile outlet			Grassed waterway			Non-ouservation			Bromegrass		
	No. of runoff events	%	Cumulative %	No. of runoff events	%	Cumulative %	No. of runoff events	%	Cumulative %	No. of runoff events	%	Cumulative %
0.000-0.005	19	53	53	12	24	24	1	4	4	3	20	20
0.005-0.010	2	5	58	8	16	40	1	4	8	0	0	20
0.010-0.050	6	17	75	15	31	71	6	25	33	2	13	33
0.050-0.100	4	11	86	3	6	77	2	8	41	0	0	33
0.100-0.500	5	14	100	8	16	93	4	17	58	9	60	93
0.500-1.000				3	6	99	3	12	70	1	7	100
1.000-2.500							7	29	99			
	36			49			24			15		

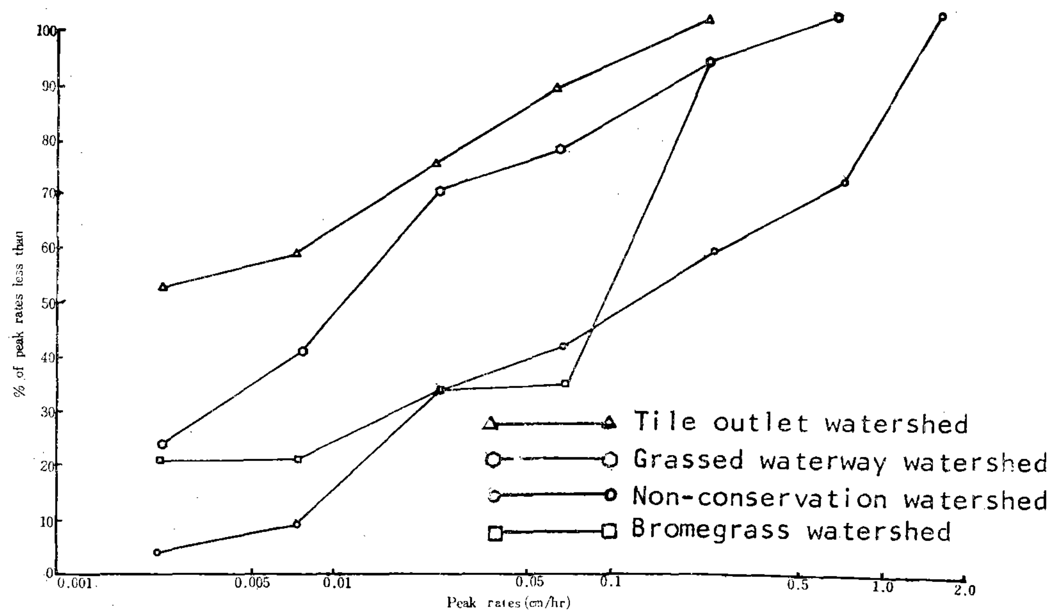


Fig.4. Distribution of peak rates of runoff by classes

3) Soil loss

The average soil loss for the period 1972-1976 was respectively 0.152 ton/ha/year, 0.191 ton/ha/year and 2.566 ton/ha/year for the Tile outlet, Grassed waterway and Non-conservation watersheds (Table-7). A great variability of sediment yields was observed among the years.

For the Tile outlet soil loss ranged from 0.003 ton/ha/year to 0.335 ton/ha/year, for the Grassed waterway from 0.002 ton/ha/year to 0.501 ton/ha/year for the Non-conservation watershed from 0.013 to 7.409 ton/ha/year.

For the Bromegrass watershed, the average soil loss for the period 1972-1974 was 0.290 ton/ha/year and ranged from 0.001 ton/ha/year to 0.615 ton/ha/year. The mean soil loss of all events, adjusted for precipitation ranged from 19.60 kg/ha/event to 602.46 kg/ha/event(Table-8)

The average annual soil loss from all watersheds was below the permissible level of 10 ton/ha/year established by the Soil Conservation Service[11] for the Sharpsburg silty clay loam soil.

This limit corresponds to the maximum rate of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely. Even the watershed with no conservation measures had losses of soil less than the 10 ton/ha limit, averaging for the period 1972-1976 only 2.566 ton/ha/year, and vary ing from 0.013 ton/ha to 7.41 ton/ha during the period 1972-1976. The relatively low rates of sediment yield are probably due to very low precipitation in two years (1974 and 1975) and below normal rainfall during the period in which the soil was tilled.

The results of 3 years of sediment monitoring at the Bromegrass watershed, and, 5 years at the Grassed waterway and Tile outlet watersheds showed that Grass represents good vegetative means of soil protection and that till-planted corn in fields protected with graded channel terraces with Grassed waterway or Tile outlet terraces are good combinations of agronomic and mechanical management practices to reduce soil erosion.

LSD test among watersheds showed that the mean sediment yield adjusted for precipitation was higher on the Non-conservation watershed. No significant differetnces were found among the three conservation watershed (Table-8).

The average annual soil loss for the Tile outlet, Grassed waterway and Bromegrass watersheds were respectively 0.152 ton/ha/year, 0.191 ton/ha/year and 0.290 ton/ha/year, which correspond to less than 10 percent of the soil loss from the Non-conservation watershed. (Table-7) The low sediment yield from both watersheds with till-plant system and terraces, demonstrate the effect of these conservation practices in controlling erosion and sedimentation. Till-planting, by leaving, crop residue on the soil surface, provides protection against the erosive action of raindrops, dissipating their energy and reducing their detachment capacity.

Terracing affects sediment yield in two ways: First,because terraces reduces the slope length, the overland flow does not reach high velocities, and consequently, has a limited power to detach particles from the soil loss. Secondaly, in the terrace channels and pondage areas of the terraces deposition of sediment occurs because the runoff moves at relatively low velocity, which reduces the transport capacity of the runoff. Very similar results

Table-7. Annual sediment yield for four watersheds

Sediment yield / Year / watershed	Sediment yield (Ton/ha)					
	1972	1973	1974	1975	1976	Average
Tile Cutlet	0.131	0.335	0.005	0.285	0.003	0.152
Grassed Waterway	0.284	0.501	0.021	0.146	0.002	0.191
Non-conservation	2.339	7.409	0.013	4.580	0.649	2.566
Bromegrass	0.002	0.615	0.001	—	—	0.290*

*Average for 3 years for Bromegrass watershed

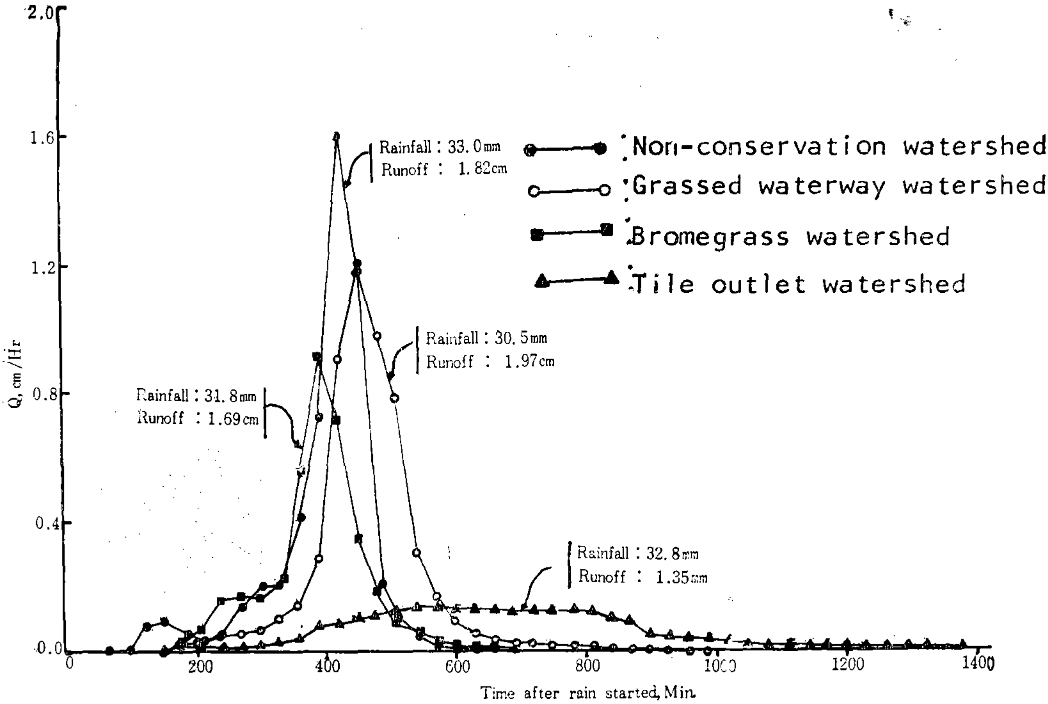


Fig. 5. Hydrographs for the Tile outlet, Grassed waterway, Non-conservation and Bromegrass watersheds (October 11, 1973)

Table-8. Covariance Analysis for sediment yield and LSD test for sediment yield means adjusted for precipitation.

Analysis of covariance for sediment yield

Source	D.F.	S.S.	M.S.	F
Regression	4	7029758.7529	1739933.1423	10.10**
Watershed	3	6513867.2874	2171239.0960	12.48**
precipitation	1	515891.4655	515891.4655	2.97
Error	119	20703843.539	174317.6781	
Corrected total	123	27733602.2920		

LSD test for the sediment yield means adjusted for precipitation (kg/ha/event)

Watershed	Sediment yield means
Tile outlet	21.43
Grassed Waterway	19.60
Non-conservation	602.46**
Bromegrass	40.98

**Highly significant

were found for sediment yield in both watersheds with till-planting, which suggest that graded parallel steep-back slope terraces and Tile outlet parallel steep back-slope terraces were equally effective in controlling soil loss when the till-planting system of crop production was used.

The low rates of erosion that occured in the Bromegrass watershed may be associated with the high efficiency of the canopy protection of the soil surface and the ability of the root system of the grasses in holding the soil together against the eroding action of the rain and runoff water. Even though the Bromegrass was heavily grazed in 1973 and 1974, the soil loss from that watershed was similar to that of the row cropped watersheds with terraces and till-plant system. In 1972, when the Bromegrass was kept ungrazed and an abundant vegetation developed during all growing season, the sediment yield from the Bromegrass watershed was negligible (0.002 ton/ha) and much less than the soil loss from the Tile outlet, Grassed waterway and Non-conservation watersheds where soil loss averaged, respectively, 0. 131 ton/ha, 0. 284 ton/ha and 2. 339 ton/ha.(Table -7).

Ⅳ. Conclusions

Runoff and soil losses were monitored from 1972 to 1976 from three watersheds with different conservation treatments and from 1972 to 1974 from a Bromegrass watershed with Bromegrass pasture without terraces. The three conservation treatments involved in the row-cropped watersheds were Non-conservation with row cropped using conventional turn plow tillage with non-terraced, Grassed waterway with steep backslope terraces and row cropped using till-planting on the contour and Tile outlet with steep back slope terraces for underground waterways and row cropped using till-planting on the contour. Specific findings of this study were summarized as follows.

1. Average precipitation for the period of study was 662mm which is 66 mm below the 76 year average for Lincoln, Nebraska. Two of the years, 1974 and 1975 were extremely dry with precipitation 300 mm below the average, two of the years, 1972 and 1976 had about average precipitation and one year, 1973 was very wet with about 240mm above the average.
2. Average annual depth of runoff for the watershed with conventional moldboard plow tillage practices (2. 44cm) was nearly identical with those from the watershed graded channel terraces, grassed waterway and till-plant practices (2. 42cm)
3. Runoff from the Tile outlet watershed was the lowest of the three row cropped watersheds, averaging for the period 1972-1976, 1. 57 cm/year which is about 35 percent less than the runoff from the Grassed waterway and Non-conservation watershed.
4. The runoff from the Bromegrass watershed were clearly affected by the grazing intensity. When ungrazed, 1972, the runoff from the Bromegrass watershed was just 0. 07 cm, which was between 7 and 19 percent of the runoff from the row cropped watersheds. When heavily grazed, 1973 and 1974, runoff averaged 4. 61 cm, which was comparable to that from the row cropped watersheds (3. 4 to 5. 18 cm)
5. The average annual soil loss from all watersheds was below the permissible level of 10 ton/ha/year, SCS allowable limit for the Sharpsburg silty clay loam soil. For the Non-conservation watershed, soil loss averaged 2.56 ton/ha/year and for the Tile outlet, Grassed waterway, and Bromegrass watershed, 0. 152, 0. 191 and 0. 290 ton/ha /year, respectively.
6. Least significant test among watersheds showed that mean sediment yield adjusted for precipitation was highly significant on the Non-conservation watershed. No significant differences were found among the three other conservation watersheds.
7. Tile outlet and Grassed waterway watershed with conservation treatments were effective in reduciug peak rates of runoff and soil loss as compared with the nonconservation treatment.

References

1. ASAE Committee on Agricultural Hydrology (1948): Effects of conservation practices on runoff. Agricultural Engineering 29(3) pp114-116.
2. Butler, R. M. (1968): The effect of tillage practices in soil and water losses from a crofton soil. Msc Thesis, University of Nebraska, Lincoln, Nebraska.
3. Foster, G.R. and L.D. meyer (1977): soil erosion and sedimentation by water, ASAE publication 4-77. St. Joseph, Michigan.
4. Johnson, H.P. and J.M. Laflen (1977): Tillage systems effects on runoff water quality, sediments and nutrients. ASAE paper No. 77-2504 A. ASAE, St.Joseph, Michigan.
5. Laflen, J.M,J.L. Baker,R,O, Hartwig, W.F. Buchele and H.P.Johnson (1976):soil and water loss from conservation tillage systems, Iowa State Water Resources Research Institute, Ames Iowa.

6. Laflen,J,M.H.P. Johnson, and R.C. Reeve (1972): soil losses from tile outlet terraces, J. of soil and water conservation 27(2): pp 74-77.
7. Piemental,D.,E.C. Terhume, R.D. Hudson S.Rochereau, R. Samis, E.A.Smith, D.Denman,D. Reifschneider, and M. Shepard (1976): Land degradation: Effects on food and energy resources. Sci. 194, pp 149-155.
8. Richardson, C.W. (1972): Changes in water yield of small watersheds by Agricultural practices, Transactions of the ASAE 15(3) pp 591-592.
9. Sharp,A.L.,A.E.Gibbs and W.J. Owen(1966)): Development of a procedure for estimating the effects of land and watershed treatment on stream flow, U.S. Dept. of Agri. Tech. Bull. N-1352
10. Smith, D.D., D.M. Witt, A.W. Zing, A. C.Mccall and F.G. Bell(1945): Investigations in erosion control and reclamation of eroded shelby and related soils at the conservation experimerimental station, Bethany, Missouri, U.S. Dept. of Agric. Tech. Bull. 883, pp1930-1942
11. Soil Conservation Service(1977): Guide to soil erosion factors and hydrologic groups of Nebraska soils. SCS state office. Lincoln, Neb.
12. Steel, R.G.D. and J.H. Torrie(1960): Ppriciples and procedures of Statistics. McGraw-Hill Book Co., Inc., New york.
13. Viessman, Jr., W.J.W. Knapp, G.L. Lewis, and T.E.Harbough(1977): Introduction to Hydrology, 2nd ed., IEP, New York.
14. Wittmuss, H.D. and N.P. Swanson (1964): Till-planted corn reduces soil losses. Agr. Eng. 45 pp 256-257.
15. Wittmuss, H.D..D.E. Lane B.R. Somerhalder (1971): Strip till planting of row crops through surface residue. Trans. of the ASAE 14(1) pp 60-63.

〔接受：1980. 12. 2〕