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Water Intake Rates of a Claypan Soil from Hydrograph Analyses[1]

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Abstract. The hydrographic analyses of rainfall-runoff data from storms occurring during the period 1945–1957 were used to estimate soil intake rates and rainfall retention. The intake rates varied from more than 2 inches to less than .01 inch per hour, depending mostly upon antecedent soil moisture and duration of the storms. Irrigation generally reduced intake rate unless accompanied by fertility treatments that greatly increased plant growth. Since the dominant factor affecting water intake was soil-moisture content, the effects of plant cover and irrigation on intake may be partly attributed to their effects on stored soil moisture. The mean values for the initial intake rates (for the first 30 minutes) and average intake rates for the 29 storms analyzed varied with antecedent moisture, management practices, and season of the year. The mean values for the final intake rates (at the end of storm) were not significantly different for the different management practices.

Introduction. Information relative to soil intake rates for different soil-moisture conditions and management practices used on different soils is of practical use in the design of both irrigation systems and flood-control structures. The rainfall-runoff data available from runoff plots and field terraces at McCredie, Missouri, presented an opportunity to study intake rates in relation to various soil-moisture, surface, and cover conditions over the 1945–1957 period.

The method of *Sharp and Holtan* [1942], with a minor modification suggested by *Zingg* [1943], was used to get estimates of intake rates from the data. This method of analysis has given valuable soil intake information for the Shelby-Grundy soils of northwest Missouri [*Jamison and Thornton*, 1959].

Procedures. Thirty-nine storms were selected as suitable for this study; according to the criteria of *Sharp and Holtan* [1942] three were classified as type A-2, six as type A-1, twenty as type B, and ten as type C. Since the type C storms were not adapted to graphic analysis, only the average retention rates and retention percentages were calculated.

The soil of the experimental areas studied is Mexico silt loam. It is a claypan soil developed in 3 to 5 feet of loess over glacial till. The surface layer is a friable silt loam, usually of weakly developed fine granular structure. The surface is underlain at about 11 to 25 inches with a clay layer (the 'claypan') that is plastic when wet but cracks and breaks into fine angular fragments when dry. This clay layer is underlain with layers of silty clay to silty-clay loam derived from the loess and till.

The treatments studied for different periods are briefly described in Tables 1 and 2. The renovation treatment consisted in seeding sweet clover and Korean lespedeza each spring in the native bluegrass sod. The plot was limed at 3 tons per acre and in March 1945 fertilized with 310 pounds of 0–14–7, and again in May 1947 with 420 pounds of 5–10–10. The contour furrows were spaced at 0.5-foot vertical, or about 15-foot horizontal, intervals.

The surface soil of the deeply fertilized plot received lime at 3 tons, rock phosphate at 1000 pounds, and sulphate of potash-magnesia at 850 pounds per acre before being plowed 10 inches deep in the fall of 1949. Lime at 3 tons and rock phosphate at 0.5 ton per acre were then placed on the plow sole and mixed in the next 6 inches by subsoiling before each furrow was turned. In the fall of 1951 this plot received lime at 3 tons, rock phosphate at 1350 pounds, muriate of potash at 100 pounds, ammonium nitrate at 200 pounds, and 0–20–20 fertilizer at 200 pounds per acre. The soil was then tilled 12 to 14 inches

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deep and seeded with a mixture of orchard grass and ladino clover. Ammonium nitrate was applied at 125 pounds per acre in November 1952.

Two orchard grass–timothy–ladino pasture plots were fertilized with urea at 30 pounds of nitrogen per acre about May 1 and again with 45 pounds of nitrogen per acre about June 20 each year for the irrigation study. One plot was irrigated as needed; the other received no irrigation. Two other orchard grass–timothy–ladino plots received no nitrogen fertilization. One of these was irrigated; the other received no irrigation.

Rainfall-runoff data for four field terrace areas were obtained during the period 1950 to date. Two of the terraces were deeply treated with lime at 4 tons per acre in August 1949. The lime was spread on the plow sole in each furrow and the subsoil shattered to 14 inches before the next furrow slice was turned. The 2-year rotation, corn–small grain with sweet clover, was grown on the terraces. Each crop was grown on

TABLE 1. Description of Pasture Treatments

Treatment	Description	Period
Pasture Improvement over Native Bluegrass		
Renovation	Native bluegrass interseeded with legumes. Moderate NPK fertilization.	1945–49
Fertilization	Native bluegrass fertilized with NPK.	1949–54
Contour furrows	Furrows at 15-foot horizontal intervals in native bluegrass.	1945–49
Brome grass–ladino, deeply fertilized	Lime, rock phosphate, and sulphate of potash-magnesia on plow sole, mixed to 16 inches by subsoiling.	1949–54
Check	Native bluegrass without fertilization.	1945–52
Orchard grass, deeply tilled	Rock phosphate, lime, and NPK fertilization, tilled 12–14 inches deep.	1952–54
Irrigation Test on Orchard Grass–Timothy–Ladino		
Water + N	Fertilized and irrigated.	1955–57
N alone	Fertilized without irrigation.	1955–57
Water alone	Irrigated without fertilization.	1955–57
Check	Without fertilizer or irrigation.	1955–57

TABLE 2. Description of Row-Crop Treatments

Treatment	Description	Period
Terraces, deeply treated	Conventional terraces limed at 4 tons/acre on plow sole, mixed to 14 inches by subsoiling.	1950–57
Terraces	Conventional terraces without subsoil liming.	1950–57

a deeply treated and an untreated terrace each year from 1950 to 1954. Since 1954 the same crop, corn or soybeans, has been grown on all the terraces.

Effect of soil management. Intake rates for the first 30-minute period for all the storms varied between more than 2 inches to less than 0.1 inch per hour. The higher rates were usually realized during hot dry summer months and the lower rates during the cooler wet spring and fall periods. Widely different rates were found for the same plots during the same year. In Figure 1 the results are shown for two different storms on the pasture plots. The first storm occurred on April 21, 1957, when the soil was very wet. It was estimated by the weather data method [*Jamison and Beale*, 1958; *van Bavel*, 1956] that the remaining available water storage capacity in the upper 2 feet of soil was about 0.6 inch.[2] Intake rates for this storm were less than 0.1 inch per hour. The soil was somewhat drier when the other storm occurred on June 29. The remaining available storage capacity was about 2.8 inches. Intake rates during the storm decreased with duration of the storm from more than 0.7 to about 0.1 inch per hour. It is evident that the differences for the two storms may be largely attributed to soil-moisture conditions. Differences in condition of the sward, in soil temperature, and in storm characteristics on the

[2] The total available water storage capacity of a soil is the quantity that can be stored between the 'field capacity' and the 'wilting point' and may be expressed as inches of water per given depth of soil. The field capacity is the quantity of moisture a soil will retain after it has been thoroughly wetted and allowed to drain until further drainage losses are very small. The wilting point is the soil-moisture content at which plants with roots thoroughly ramifying the soil mass will wilt without recovering in a humid atmosphere.

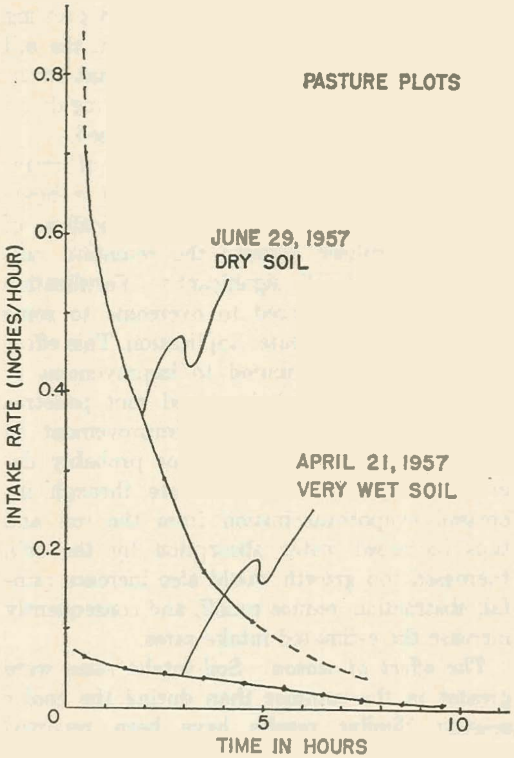

Fig. 1. Changes in intake rate with storm duration for storms occurring on pasture plots at two different moisture conditions.

two dates may also have contributed to the intake rate differences found.

Intake rates at the cessation of runoff for all the storms analyzed varied between 0.15 and .005 inch per hour. Since these values were not significantly affected by pasture or row-crop management practices, they are not included in the tables.

The results for the various management practices tested on pasture plots are shown in Table 3. The renovation treatment, which involved interseeding of native bluegrass with legumes together with moderate fertilization, did not significantly increase the average retention percentage or the average intake rate. However, the average intake rate for the first 30 minutes of the storms was increased significantly. The contour furrows also significantly increased the observed initial intake rates. This was probably the result of abstraction due to water-trapping by the furrows, which effect was included in the computed intake rates. The increase in percentage retention approached significance. Fertilization of bluegrass sod significantly increased percentage retention and average intake rate, though the increase in the initial intake rate was not significant.

TABLE 3. The Influence of Various Pasture Management Practices on Rainfall Retention and Soil Intake Rates for Mexico Silt Loam

Treatment	Retention, per cent	Intake Rates: First 30 Min, inches/hour	Intake Rates: Average, inches/hour
Bluegrass check	56.1	0.48	0.25
Renovation	60.7	0.56*	0.26
Contour furrows	61.7	0.56*	0.26
Bluegrass check	59.6	0.37	0.34
Bluegrass, fertilized	76.2*	0.47	0.37†
Brome-ladino, deeply fertilized	80.1†	0.49	0.39†

* Within the .05 to .01 probability range and considered significant.

† Less than .01 probability and considered highly significant.

Deep treatment with lime and the establishment of a brome grass–ladino sod significantly increased percentage retention and average intake rate in comparison with surface-fertilized bluegrass. The increase in the initial intake rate approached significance.

The average intake rate and percentage of retention were not significantly greater for orchard grass pasture that had been deeply tilled before seeding than for native bluegrass sod with fertilization (Table 4). Deep treatment with lime did not significantly increase average intake and retention under row crops in field terraces. Subsoiling without deep fertilization of this claypan soil was found to decrease crop yields [*Woodruff and Smith,* 1946]. This effect may be attributed to some mixing of acid clay subsoil with the more fertile silt loam of the surface and possibly to some breaking up of subsoil structure. Adding lime to the subsoil seemed to offset these detrimental effects.

It appears that deep tillage, with or without deep liming treatments, has little over-all lasting effect on rainfall retention by this soil. There were appreciable increases in the intake rates

TABLE 4. The Effect of Deep Tillage and Fertilizer Treatments on Retention and Intake Rates

Treatment	Retention, per cent	Intake Rates: First 30 Min, inches/hour	Intake Rates: Average, inches/hour
Pasture			
Bluegrass, fertilized	93.9	2.25	0.69
Orchard grass, deeply tilled*	95.8	2.50	0.71
Row Crops on Terraced Land			
None	82.0	1.49	0.49
Deeply treated (lime mixed to 14 in.)	82.4	1.49	0.46

* Tilled about 14 inches deep before seeding to pasture.

on the deeply treated areas over the untreated areas during short periods when sweet clover was grown in rotation with row crops. For the period July 12, 1951, to April 4, 1952, while sweet clover was on the land, the deeply treated plots retained 78.3 per cent and the check plots 74.4 per cent of the 26.0 inches of rain that fell during the period. However, since retention was a little less for the treated plots during other periods, when corn, oats, and corn stalks were on the land, there was no significant average difference in rainfall retention. The sweet clover roots were observed to penetrate somewhat deeper into the treated subsoil. This may have resulted in some improvement in soil structure and in an increase in moisture intake. Reduction of the measured runoff through interception by the clover crop would also affect the intake rates obtained. Probably the most important factor affecting the increase of intake rates was the reduction in soil moisture by the crop.

In general, those fertility treatments and plant species which resulted in improved sward quality with more vigorous top and root growth were associated with higher intake rates. Increased abstraction by increased plant cover and improvement in soil structure through increased root growth may be partly responsible for the differences. It is also possible that differences in soil-moisture content at the time of rainfall resulted from the treatments. An actively growing sward will remove more moisture from the soil profile than a sparse and dormant plant cover. This should be particularly true if rooting depth and ramification in the soil are increased.

The effect of irrigation. The effect of irrigation on retention and intake for pasture is shown in Table 5. Water without the application of nitrogen fertilizer reduced the retention percentage of rainfall significantly. Fertilization with nitrogen appeared to overcome to some extent the effect of water application. This effect may be partly attributed to improvement of soil structure through increased root penetration and growth. However, improvement in extent of cover and plant vigor probably decreased antecedent soil moisture through increased evapotranspiration from the soil and thus increased water absorption by the soil. Increased top growth would also increase rainfall abstraction, reduce runoff, and consequently increase the estimated intake rates.

The effect of season. Soil intake rates were greater in the summer than during the cooler seasons. Similar results have been reported for Marshall silt loam in Iowa [*Bertoni, Larson, and Shrader*, 1958]. Because of the increase in fluidity of water with temperature, the rate at which a soil will absorb moisture should be approximately double for a temperature increase of 25°C [*Fletcher*, 1949; *Wisler and Brater*, 1940].

Since grazed pastures would be less subject to differences in ground cover than other crops, the data from the native bluegrass pasture were

TABLE 5. The Effect of Irrigation and Nitrogen Fertilization on Percentage Rainfall Retention by Pastures on Mexico Silt Loam

Treatment	Retention, per cent	Intake Rates: First 30 Min, inches/hour	Intake Rates: Average, inches/hour
None	80.0	0.76	0.23
Nitrogen alone	79.7	0.87	0.24
Water alone	68.2*	0.74	0.18
Water plus nitrogen	74.7	0.78	0.21

* Less than .01 probability level and considered a highly significant decrease for irrigation.

TABLE 6. Estimated Available Soil Moisture Content, Moisture Fluidity, and Intake Rates for 29 Storms on Native Bluegrass Pasture

Date of Storm	Mean Air Temperature, °F	Moisture Fluidity (F), poises^{-1}	Available Soil Moisture (M), inches/2 ft	Initial Intake Rate (f_i), inches/hour
5-14-45	70	102	2.8	0.30
6- 7-45	68	100	3.1	.58
6-30-45	74	107	1.6	.2
9-21-45	65	96	1.6	1.4
9-28-45	66	97	3.4	0.18
5-10-46	63	93	3.3	0.40
11- 2-46	57	86	2.6	0.20
11- 9-46	43	68	3.4	0.22
6-21-48	71	103	2.4	0.40
7-22-48	77	112	3.2	0.46
8-27-48	75	110	1.6	2.2
11- 2-48	62	90	2.2	0.7
3-30-49	63	93	3.3	0.10
9-12-49	67	97	1.9	1.3
3-17-51	38	63	3.0	0.15
5- 9-51	64	95	0.5	2.7
9-21-51	70	102	2.4	0.7
10-23-51	47	72	2.7	0.4
5- 4-53	53	81	2.9	0.4
5-22-53	74	107	0.9	2.0
4- 4-55	62	90	1.3	1.2
4-23-55	64	95	1.2	2.0
6-24-55	68	100	2.0	0.8
7-14-55	76	111	1.3	1.8
8- 7-55	75	110	1.8	0.7
7-15-56	81	117	2.5	0.7
4-21-57	64	95	2.6	.07
6-29-57	71	104	1.9	1.0
6-30-57	64	95	2.4	0.23

used to determine the relationship of water fluidity corresponding to the air temperature on the day of a storm and the estimated available soil moisture in the upper 2 feet of soil. For about the same plant-cover conditions the two factors that affect intake should be soil moisture and temperature. These were not measured on the pasture runoff plots at McCredie. However, weather records including air temperatures are available. By assuming that the soil surface temperature at the beginning of the storm would be proportional to the average air temperature for the day a given storm occurred and by estimating antecedent available moisture content for each storm by the use of other weather data [*Jamison and Beale*, 1958; *van Bavel*, 1956], both factors can be evaluated reasonably well. The average daily air temperatures, the available soil moisture contents, and the first 30-minute intake rates are shown in Table 6 for the 29 storms analyzed. The water fluidity values were taken from published data on changes in the fluidity of water with temperature [*Hodgman*, 1954–55].

The method of least squares was used to obtain the exponential equation $f_i = 0.0018\ F^{1.82}/M^{1.57}$, where f_i is the average intake rate for the first 30 minutes of a storm, F the fluidity of water in reciprocal poises, and M the computed antecedent available soil moisture content in the upper 2 feet of soil. For the data used, the multiple correlation coefficient for f_i with F and M was 0.82 and for f_i with M, −0.79. Since there were 29 samples these values are highly significant at the 1 per cent probability level. The correlation coefficient of f_i with F was 0.45 and significant at the 5 per cent probability level. From the equation, values of f_i at 10°C are approximately half those at 35°C for the same M values. This is in general agreement with the work of *Fletcher* [1949], who found a relationship between the first 15-minute intake rate and the temperature of the surface 3-inches of several Arizona soils. His derived curve indicates a doubling of intake as the temperature increased by about 35°C.

Conclusions. The dominant factor determining soil-moisture intake rate for the Mexico silt loam studied is moisture content. The temperature of the soil surface during a storm also influences intake rate, and perhaps soil fertility does also. With the exception of irrigation, those treatments that improve plant growth also appear to increase intake rates for Mexico silt loam. These increases may be due in part to structural improvement of the soil surface and in part to a reduction in soil-moisture content. Also, increased plant cover will increase rainfall abstraction and decrease runoff and thereby increase the apparent intake by the soil. Over the range of conditions provided by the various treatments during the period of these studies, soil conditions resulting from different management practices have played minor roles in determining intake rates.

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