Relation of Plant Cover to Infiltration and Erosion in Ponderosa Pine Forests of Colorado

E. J. Dortignac and L. D. Love

PONDEROSA pine forests cover more than half of the timbered lands in Colorado. This forest zone occupies most of the Colorado Front Range, the easternmost range of the central Rocky Mountain system. Here ponderosa pine is found at elevations between 6,500 and 9,000 feet.

Land features consist of ridges, mountain slopes, steep rocky canyons, foothills, narrow mountain valleys, and large openings or parks. Most soils originate from granites, which disintegrate readily and produce soils that erode easily when exposed. Soils derived from schist are next in extent but occupy considerably less land. Soils of sedimentary origin are minor.

Climate of the ponderosa pine forest is variable. Most of the precipitation (17 to 22 in. a year) falls as rain during April through October. Light afternoon showers are common from July through September, but on the average about five storms have sufficiently high intensities to produce surface runoff. Maximum rainfall rates have exceeded 6 in. per hour for 5-min durations; intensities in excess of 4 in. per hour for 5-min intervals are frequent.

Ponderosa pine in various mixtures with grass or weeds is the most common vegetation cover. Three cover types are (1) dense stands of pine with closed canopies and a ground cover of pine litter, (2) parks and other small openings consisting of herbaceous vegetation, mostly grass, and (3) pine-grass, an open forest of trees, with a ground cover of herbaceous vegetation and pine litter. Stands of aspen are found scattered along valley bottoms, on benches, at heads of small drainages, and on old burns, while brush grows at the lower elevations, on south exposures, and on old burns. Mixed conifer (Douglas – fir, pine, and spruce) and lodgepole pine occur mostly on north exposures and on the more moist sites.

The purpose of this paper is to make available some of the findings obtained with the Rocky Mountain infiltrometer at the Manitou Experimental Forest, particularly as related to plant cover and erosion indices. Another purpose is to compare infiltrometer results with plot data on runoff and to discuss the factors involved. A third objective is to propose watershed criteria for the ponderosa pine forest in the Colorado Front Range based on infiltrometer and runoff plot studies.

Paper presented at the Annual Meeting of the American Society of Agricultural Engineers at Santa Barbara, Calif., June 1958, on a program arranged by the Soil and Water Division.

The authors—E. J. DORTIGNAC and L. D. LOVE—are foresters (research), Rocky Mountain Forest and Range Experiment Station, Forest Service, USDA, stationed respectively at University of New Mexico, Albuquerque, and Colorado State University, Fort Collins.

* Numbers in parentheses refer to appended references.

FIG. 1 Rocky Mountain infiltrometer installed on a grassland site at Manitou Experimental Forest. Rainfall simulator equipped with three type F nozzles. Rain troughs are located on both sides of the 2.5 sq ft plot.

Rocky Mountain Infiltrometer

The Rocky Mountain infiltrometer used for measuring infiltration and erosion is a portable apparatus with a rainfall simulator (Fig. 1). The small plot size (2.5 sq ft) allows taking a large number of samples.

A complete description of the design, operation, and use of the Rocky Mountain infiltrometer is available (1)*. Water is sprinkled on the infiltrometer plot and surrounding area covering about 40 sq ft. Applying water to such a large area reduces lateral movement of water through the soil. The sprinkling device consists of three type F nozzles that maintain a 7-ft fall at working pressures between 20 and 30 lb. Rainfall rates used in these experiments averaged 4.50 in. per hour except on a few plots where a rate of 7 in. per hour was required to produce runoff.

Infiltration Rates

Runoff and artificial rainfall were measured volumetrically at 5 or 10-min intervals. Runoff usually commenced after 3 to 5 min of sprinkling, indicating that initial wetting, interception, and depression storage were largely satisfied by this time.

Infiltration rates (f_c)are the average rainfall minus runoff rates obtained in the last 20 min of a 50-min sprinkling application on prewetted soils. This rate is similar and highly correlated with the f_b rate measured during the first 30 min of artificial rainfall. Infiltration rates of individual plant-soil complexes average lower for the f_c rate under wet surface-soil conditions than under dry soil conditions.

Erosion Indices

The Rocky Mountain infiltrometer was originally designed to measure the rate of infiltration, but with use it became apparent that total soil loss during a test run would provide an index of soil erodibility. Soil loss per unit volume of surface runoff gave an index of soil erodibility caused by splash or rainfall impact at the particular spot sampled with this instrument.

Erosion from plots with prewetted soils was most consistent. More than 1 in. of runoff in an hour was needed to develop a consistent index of soil erodibility.

Erosion index is expressed in pounds per acre per inch of runoff and provides a measure of soil removal per unit volume of runoff. The total soil loss during a field test or during a rainstorm is directly dependent upon and related to that portion of the applied or natural rainfall that exceeds the infiltration rate of the soil.

In all tests with the Rocky Mountain infiltrometer since 1950, both erosion and infiltration have been measured. The erosion indices are based on tests conducted at the Manitou Experimental Forest and on the Roosevelt National Forest west of Loveland, Colo., from 1950 through 1954.

Relation of Plant Cover to Infiltration

At Manitou Experimental Forest and elsewhere in the Colorado Front Range it was found that on grazed areas infiltration varied with cover type. For example, in the 1700-acre grazed range pastures on alluvial soils, grassland had the lowest infiltration rate and pine litter the highest, with pine-grass intermediate (Fig. 2). The observed differences were larger than could have occurred by chance, as the standard error of the difference was ± 0.16 in. per hour.

On the steeper slopes in the Missouri Gulch watershed at the Manitou Experimental Forest, residual soils derived from granite had higher average infiltration rates than on the alluvium. Here, aspen sites had a higher rate of water intake than either pine-grass or browse (mostly mountainmahogany) sites. Grazing by cattle was moderate from 1941 to 1954.

A similar relation of infiltration to cover type was found elsewhere in the Front Range. On the Roosevelt National Forest (4), the same relative order was obtained though cover type values averaged higher:

Cover Type	Infiltration Rate (f_c) Roosevelt (residual—granite—schist)	Manitou (alluvium—granite)
	Inches per hour	
Grassland	1.60	1.50
Pine-grass	2.04	1.94
Pine litter	3.68	2.37

The pine litter type on the Roosevelt National Forest has an overstory of lodgepole pine and Douglas-fir in contrast to Manitou, where the overstory is ponderosa pine. This may account for the higher infiltration rates.

Relation Between Grass Species and Infiltration

Even within cover types, variation in infiltration rate may be associated with plant composition. As an illustration, in grassland in the range pastures at Manitou it was found in the 1946 tests that infiltration varied with dominance of individual grass species. The main grass species on infiltrometer plots was mountain muhly, but Arizona fescue was predominant on enough plots to provide a comparison. Average infiltration rates with respective confidence limits at 99 to 1 odds were:

Dominant species	Infiltration rate (f_c)	Expected Range Upper	Lower
	Inches per hour		
Arizona fescue	3.05	3.75	2.35
Mountain muhly	1.55	1.85	1.25

On the average, plots supporting Arizona fescue had about double the water absorption rates of those covered with mountain muhly.

Blue grama was predominant on only a relatively few of the plots tested in 1946, but on these, infiltration rates averaged only 1.29 in. per hour. These results are in agreement with earlier studies of Johnson and Niederhof (3) who concluded that blue grama sod when present on soils of naturally high infiltration rates, tends to decrease the rate of water absorption. A similar effect was observed in western Colorado with Kentucky bluegrass, another sod-forming grass (6).

Relation of Infiltration to Vegetation and Soil Properties

Infiltration rates were associated with vegetation type because organic materials and physical soil properties varied with cover type. In the range pastures, live and dead aboveground organic materials, soil texture, porosity, and water-holding capacities varied by cover type. Pine litter had the most porous surface soil conditions and the greatest quantity of dead organic material (litter). Litter and porosity of the surface soil were the two measured factors most highly and consistently associated with infiltration rates throughout the period of study. The variation in litter and large pore space of the upper 2 in. of soil in the grazed range pastures varied by cover type, as follows:

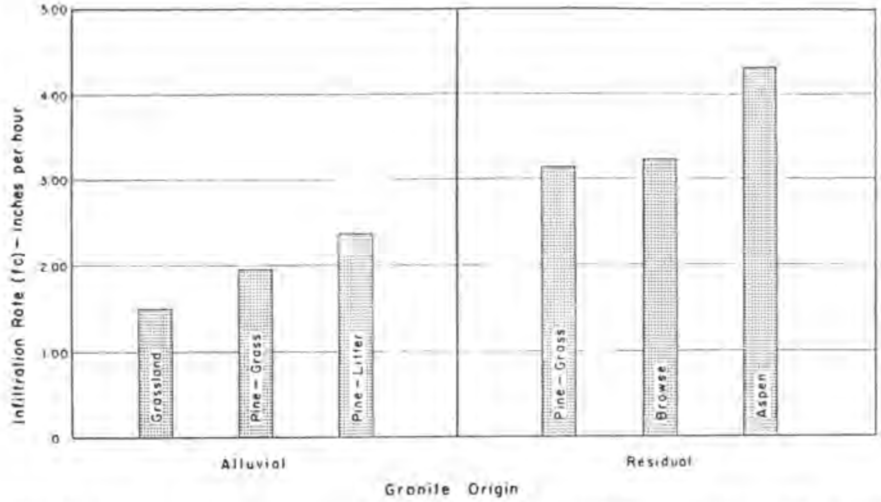

FIG. 2 Average infiltration rates at Manitou Experimental Forest under cattle-grazed conditions.

Cover type	Litter, tons per acre	Large (non-capillary) pores, percent of volume
Grassland	2.4	19.9
Pine-grass	4.4	25.1
Pine litter	10.4	30.0

Effect of Protection from Grazing on Infiltration

Litter accumulation in grassland and pine-grass areas grazed by cattle was less than in the 2.5-acre fenced plots where livestock were excluded. Likewise, the upper 2 in. of soil had a smaller percentage of large non-capillary pores under grazed conditions. These differences were reflected in the average infiltration rates obtained under grazing as compared with those under protection from grazing.

The recovery or increase in infiltration rate after 14 years protection from grazing was most pronounced in the grassland:

Cover type	f_c infiltration rate, inches per hour 1941	1954
Grassland	1.95	3.26
Pine-grass	1.59	2.60

Relation of Plant Cover to Erosion

Total annual soil erosion occurring over a site or a watershed is a function of the quantity and distribution of runoff and the erodibility of the soil. Erosion measured by the infiltrometer provides an index of the ease of soil dislodgement by rainfall impact for specific soil types and plant cover conditions. Combining the erosion index with the estimated runoff determined from infiltration rates or measured surface runoff provides an indication of probable soil losses from sheet erosion over a given area.

The erosion indices determined at Manitou with the infiltrometer varied with cover type, (Fig. 3), but not in the same sequence as infiltration rates. Aspen cover had the highest infiltration rate and the lowest erosion index. But browse, with the next highest infiltration rate, had the highest erosion index.

Influence of Organic Materials on Erosion Indices

Soil losses on agricultural lands have been shown to be related to length and degree of slope, energy dissipated by falling raindrops, velocity and volume of runoff, soil type, organic materials, and land treatment. In the ponderosa pine belt of the Colorado Front Range, the quantity and the distribution of organic materials overlaying the soil mantle have the greatest influence on erosion. The amount of bare soil exposed to the direct impact of raindrops is strongly related to the erosion rate and provides a useful indication of potential erosion. For conditions sampled, soils derived from granitic rocks had the lowest erodibility; those from schist, the highest, with soils from granite-schist, intermediate. A similar relationship was found among individual infiltrometer plots within cover types. When combining grassland with pine-grass, the two cover types with the lower infiltration rates, the following was obtained:

Exposed soil, percent	Roosevelt (granite—schist residual) Erosion index, pounds per acre per inch of runoff	Manitou (granite—alluvium) Erosion index, pounds per acre per inch of runoff
0-9	170	96
10-29	440	194
30-69	1200	289

Reliability of Infiltrometer Data

Infiltration and erosion indices as measured with the Rocky Mountain infiltrometer vary with plant cover conditions in the ponderosa pine forests of Colorado. Whether these measured rates are valid and represent those experienced under natural rainstorms is important to both land managers and engineers. Land managers are primarily interested in learning how these evaluations may be used to set safe criteria for management of watershed lands to avoid on-site as well as downstream damage. On the other hand, the engineer wants to know whether values obtained can be used to accurately predict runoff, erosion, and sediment from watershed lands under existing or changed conditions of plant cover, soil, and microclimate.

An idea of the possible effect of plot size on infiltration rate was studied by Wilm (7). A comparison of infiltration rates obtained with the type F and Rocky Mountain infiltrometer, both employing type F sprinkler nozzles, indicated reasonable agreement. In this study, 30 comparisons were made between the 79 sq ft (6.6 ft x 12 ft) type F and the 8 sq ft (2 ft x 4 ft) Rocky Mountain infiltrometer. (The size of this infiltrometer was later cut down to 2.5 sq ft.). There was a highly significant relation between infiltration rates obtained with these two instruments and mean values were 2.80 and 2.44 in. per hour for the large and small plots, respectively.

Surface runoff plots, measuring 6.6 by 66 ft and enclosing 0.01 acre, were installed in open grassland in 1937 and under second growth ponderosa pine in 1938. Complete description of these installations and resultant surface runoff and erosion have already been reported (2). Both installations were on an alluvial bench on 17.5 percent slopes with north exposures. Rainfall intensity was recorded but only total runoff and total erosion were measured after each storm period.

On both sets of plots, livestock and men were excluded from the time of establishment until 1941. Grazing treatments were applied to some of the bunchgrass plots and ground litter removed from half of the pine plots in 1941.

Since rainfall intensities were measured, it was possible to compute an average retention rate as an approximation of the infiltration rate for each plot and rainstorm producing runoff. The method involves computation of rainfall intensities for each change in rate. Rainfall intensities in inches per hour were plotted graphically (Fig. 4) for rainstorms with 1 in. or more of total rainfall. Total storm runoff was converted to area-inches. The average storm retention rate necessary to produce rainfall excess equal to runoff in inches was determined graphically as in Fig. 4.

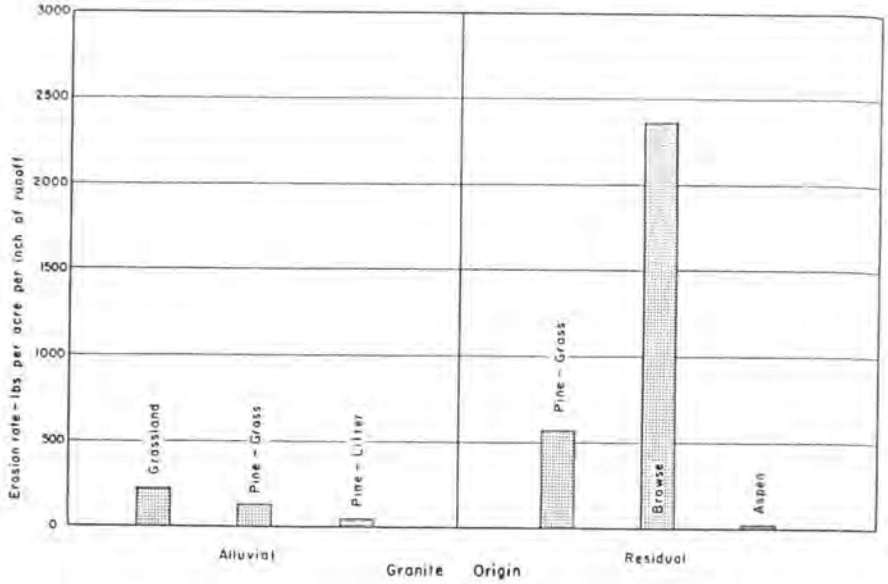

FIG. 3 Average erosion rates at Manitou Experiment Forest under cattle-grazed conditions.

During the post-treatment infiltration study period (1944-54) there were only seven storms with 1 in. or more total rainfall recorded at the bunchgrass runoff plots. The average retention rates from these storms were compared with infiltration rates measured with the infiltrometer in grassland over the 1700-acre grazed pasture area. These comparisons for the extreme plant-soil conditions sampled were as follows:

Plant-soil condition	Runoff plots, 1944-1953	Infiltrometer plots in range pastures, 1946-1954
	Inches per hour	
Heavily grazed	1.69	1.23
Not grazed	2.68	2.67

The only available comparison of infiltrometer results with those from the pine runoff plots are the infiltration rates of lightly grazed pine litter plots in the range pastures. There were ten storms exceeding 1 in. total rainfall between 1941 and 1947 at the pine runoff plots. Average retention rates for runoff plots and infiltration rates for infiltrometer pine litter plots are compared, as follows:

Runoff plots— No treatment		Infiltrometer— pine litter plots	
Year	Inches per hour	Year	Inches per hour
1941	3.10	1941	2.56
1942	2.40	1942	2.07
1944, 1945, 1947	3.35	1946	2.86

Retention rates on runoff plots would be expected to average somewhat higher because pine saplings intercepted some of the high intensity rainfall, whereas none of the artificially applied rainfall was intercepted by tree foliage on the infiltrometer plots.

The general agreement of infiltration rates obtained with the infiltrometer with retention rates from runoff plots for similar plant-soil conditions is noteworthy since mean values obtained represent different sites. In California, Rowe (5) was able to predict with considerable success the quantity and rate of surface runoff on 1/40-acre hillside plots by using infiltrometer data taken at the same location.

Estimating Total Soil Loss on Runoff Plots from Infiltrometer Erosion Indices

The erosion indices measured with the infiltrometer were checked against actual measured soil losses from run-

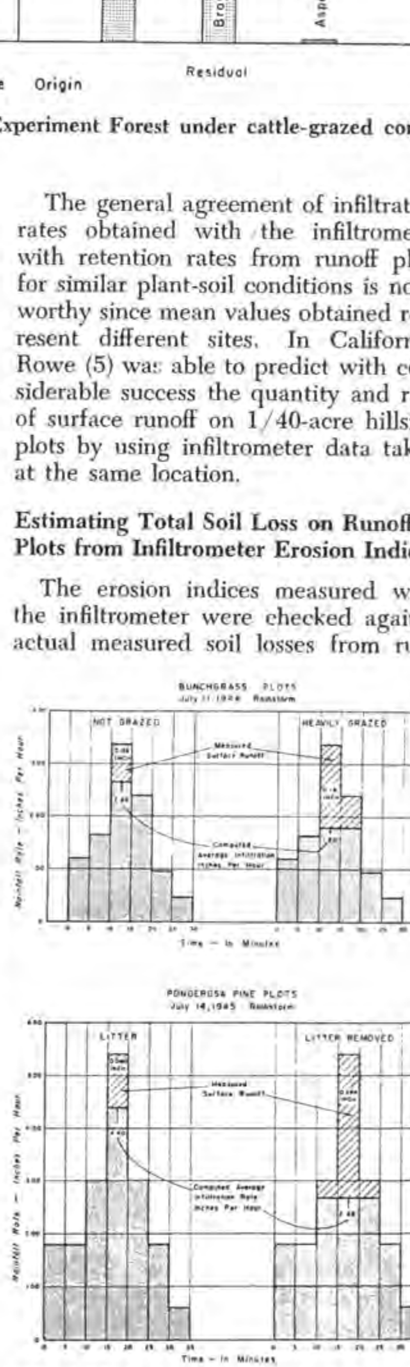

FIG. 4 Method used in calculating the average storm infiltration rate from surface runoff.

off plots. Since the area of exposed soil was never measured on the runoff plots, there is no way of comparing erosion rates obtained on these runoff plots with estimated indices based on the bare soil-erosion relationships developed with the infiltrometer. It is possible to compare total soil losses actually measured from runoff plots with computed soil losses by using erosion indices determined from infiltrometer tests, provided reasonably similar plant-soil conditions are evaluated.

In half of the 16 years of study (those before treatment) there was no measurable erosion from the bunchgrass runoff plots. Measurable erosion following the initiation of grazing treatments occurred mainly during the months of July and August, the same time when infiltrometer measurements were taken. It was noted on runoff plots that most erosion occurred when large storms followed one another at short intervals. By the use of the average erosion indices from grassland in the Manitou pastures in 1952, and those from grassland inside exclosures in 1954 for nonuse, the following comparison of soil losses per storm producing erosion is made:

Grazing Use	Total soil loss (pounds per acre) from runoff plots	
	Measured	Computed from infiltrometer data
Heavy	316	235
Moderate	145	145
None	134	20

The only large discrepancy is for the no-grazing treatment.

Watershed Criteria

On the basis of infiltrometer tests, corroborated by plot runoff data, satisfactory watershed criteria may be established for the ponderosa pine forests in Colorado. In general, where on-the-ground organic materials exceed 2 tons per acre and where more than 22 percent of the volume of the upper 2 in. of soil is large (noncapillary) pores, infiltration rates will be sufficiently high to restrict surface runoff to small quantities.

Acceptable erosion indices, from the standpoint of watershed management, will depend on the infiltration rate of the plant-soil complex. For example, the relatively high erosion index under browse cover is of little consequence because the infiltration rate is high enough to absorb high intensity rainfall.

In general, when sheet erosion indices as measured with the infiltrometer are less than 500 lb per acre per inch of runoff and f_c infiltration rates exceed 1.50 in. per hour, relatively small amounts of soil will be washed from slopes in the ponderosa pine forest, particularly as compared with soil losses from croplands. On soils derived from granite, only the browse and pine-grass types exceeded this index of erosion. On soils developed from granite-schist, all vegetation types sampled averaged less erosion than 500 lb per acre per inch of runoff. On soils of schist origin, only depleted grassland cover had average erosion indices exceeding this amount.

Summary

The Rocky Mountain infiltrometer was used to evaluate infiltration and erosion of the most common vegetation cover types found in the ponderosa pine forests of Colorado. Almost 750 tests were conducted at the Manitou Experimental Forest under grazed conditions. One-third as many tests were made elsewhere in the South Platte River watershed and on the Roosevelt National Forest, west of Loveland, Colo.

On the basis of these tests it was found that infiltration rates varied with cover type. Large pore space of the upper 2 in. of the soil and the quantity of dead organic materials were the two properties that accounted for most of the variation in infiltration rates among cover types.

Erosion indices also varied with cover type, but soil origin and the amount of exposed or bare soil were the main factors affecting erosion.

Infiltration rates increased 1.31 in. per hour is grassland and 1.01 in. per hour in pine-grass after 14 years of protection from grazing at Manitou Experimental Forest.

Infiltration and erosion indices measured with the infiltrometer in the range pastures were compared with rates computed from adjacently located runoff plots. Even though measurements were made at different locations in the Manitou Experimental Forest, infiltration and erosion determined with the infiltrometer compared favorably with results obtained on runoff plots for similar plant-soil conditions.

Criteria are proposed for determining satisfactory infiltration rates and acceptable quantities of erosion in the ponderosa pine forests of Colorado utilizing results from infiltrometer tests and runoff plots.

References

1 Dortignac, E. J. Design and operation of Rocky Mountain infiltrometer. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Station Paper 5, 68 pp., illus., 1951.

2 Dunford, E. G. Surface runoff and erosion from pine grasslands of the Colorado Front Range. Jour. Forestry 52:923-927, illus., 1954.

3 Johnson, W. M. and Neiderhof, C. H. Some relationships of plant cover to run-off, erosion, and infiltration on granitic soils. Jour. Forestry 39:854-858, illus., 1941.

4 Reid, E. H. and Love, L. D. Range-watershed conditions and recommendations for management, Elk ridge and lower Elk ridge cattle allotments, Roosevelt National Forest, Colorado. U.S. Forest Service, 123 pp., illus., 1951.

5 Rowe, P. B. Influence of woodland chaparral on soil and water in central California. California Department Natural Resources Division of Forestry, 70 pp., illus., 1948.

6 Turner, George T. and Dortignac, Edward J. Infiltration, erosion and herbage production of some mountain grasslands in western Colorado. Jour. Forestry 52:858-860, 1954.

7 Wilm, H. G. The application and measurement of artificial rainfall on types FA and F infiltrometers. Amer. Geophys. Union Trans., Pt. II: 480-484, illus., 1943.

NEW CONCEPTS IN IRRIGATION EFFICIENCY

(Continued from page 57)

is primarily because of the capacity of a plant to extract more water from the upper portion of the root zone than from the lower portions. Alternating the depth of application also promotes better bacterial growth in fine textured soils.

Also, water application and distribution efficiencies of nearly 100 percent are not always desirable or practical. The expense necessary to secure high application and distribution efficiencies is often in excess of the economic returns. Another important reason for not always desiring water application efficiencies of nearly 100 percent is that one or more excessive applications of water per year, depending upon the salt content of the water and soil, is usually desirable to flush out excess salts in the root zone, thereby keeping the soil in a good productive condition.

Conclusions

Adequate control and management of irrigation water requires that methods be available to evaluate the irrigation practice from the time the water leaves the point of diversion until it is utilized by the plant.

The concept of water conveyance efficiency adequately evaluates the conveyance phase and the concept of water application efficiency adequately describes the tendency for excess application. Both concepts have been, and will continue to be, extremely useful.

Three new irrigation efficiency concepts have been proposed to aid in controlling the irrigation practice. Water storage efficiency is useful whenever insufficient water is applied to the root zone during the irrigation; water distribution efficiency evaluates the uniformity with which the water is distributed throughout the root zone; consumptive use efficiency measures the ability of the roots to utilize the moisture placed in the root zone during irrigation.

All five aspects of irrigation efficiency are needed to adequately describe the irrigation practice and to focus attention upon the methods which must be

(Continued on page 64)