PRECIPITATION, RUNOFF, AND SOIL MOISTURE RELATIONSHIPS AT A.R.E.C. BEQA'A, LEBANON

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RUNOFF AND SOIL MOISTURE

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AN ABSTRACT OF THE THESIS OF

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A two year experiment was conducted at the Agricultural Research and Education Center of the American University of Beirut, Beqa'a, Lebanon, to study runoff and its relationships with different parameters of rainfall (rain depth, kinetic energy, and Erosion Index), percent slope (2.5, 3.5, and 4.5), length of slope (30 meters and 60 meters), and crop cover (wheat, fallow, and vetch).

Concurrently the consumptive use of the crops (wheat and vetch), evaporation from fallow land, and deep percolation during the year 1967-68 were determined by the use of neutron scattering method for soil moisture measurement and application of Penman formula for estimation of consumptive use during the winter months.

The total amount of runoff during year 1966-67 ranged from 8.67 mm to 23.58 mm or 1.47% to 3.99% of the total precipitation. The corresponding values for the second year were 8.7 mm to 21.21 mm or 1.58% to 3.83% of the total precipitation. The parameter of rainfall which was most closely related to runoff was Erosion Index, while rain depth was the least correlated. The percent slope did not affect the runoff significantly under the rainfall intensities experienced over the slope range of the plots. Amount of runoff per unit area over the long plots was 50% of that on the short plots. The different crop covers did not result in substantial differences in runoff.

The total consumptive use for wheat and vetch during year 1967-68 was 21.9 cm and 23.5 cm, respectively, while the total evaporation from the fallow plots was 24.5 cm over the same period. The peak rate of water use for wheat and vetch was in the first two weeks of April.

Fallowing practice in the first year resulted in conserving moisture, but fallowing for two consequtive years did not improve the storage of moisture and is not, therefore, necessary. The wheat and vetch crops extracted moisture mainly from the top 50 cm layer of the soil and effective rooting below 50 cm was not appreciable.

The amount of deep percolation, occurring mainly from December to early March ranged from 24.9 cm to 26.8 cm or 49.58% to 52.26% of the total precipitation from vetch and wheat plots, respectively.

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I. INTRODUCTION

Knowledge of the different segments of the hydrologic cycle, which is the study of distribution and circulation of water, is of prime importance in agriculture.

In its simplest form it can be represented by the following formula: $P = R + Et + D.P. + \Delta$, in which P is precipitation, R is runoff, Et is evapotranspiration, D.P. is deep percolation and Δ is change in soil moisture content.

The importance of runoff in the field of soil and moisture conservation has resulted in extensive research programs to investigate its relationships with various independent variables which affect it viz ; rainfall depth, rainfall energy, percent slope, length of the slope, soil physical properties, vegetation and past history of land use. The ultimate goal of all these research programs is the development of a universal equation for prediction of runoff on the basis of these variables and adopting the most adequate conservation practices.

Available information on the use of water by winter crops and the effect of fallowing in conserving moisture for crops to stabilize yields, is also valuable for making decisions on rotation programs in dryland farming. This study was undertaken with the following objectives:

1. To determine the amount of runoff under the rainfall pattern and prevailing conditions in Beqa'a Plain.

2. To investigate the dependence of runoff on percent slope and length of slope.

3. To gain information on the effectiveness of plant cover on reducing runoff.

4. To understand the efficiency of fallowing in conserving moisture for the following crop.

Concurrently the related fields of consumptive use of the crops and deep percolation were considered. It is hoped that this study will encourage further experimentation in the field of soil and moisture conservation in order to clarify the relative roles of the individual factors and their complex interactions, on runoff and soil loss.

II. REVIEW OF LITERATURE

Runoff

Definition

Runoff is defined as that portion of the precipitation that makes its way towards stream channels, lakes and oceans (Schwab, 1966, pp 56). In this study the term runoff refers only to the water lost as surface flow. There are several factors that affect the loss of precipitation as runoff. Scientific farm planning requires a knowledge of the effects of individual factors and their interrelationships. Extensive research programs have been carried out in the U.S.A. and elsewhere since 1930 (Wischmeier, 1966), to investigate these factors and their interactions.

Comprehensive analysis of 8,000 to 10,000 plot years of data from these studies show that the total runoff from cropped plots in soil erosion studies varied from 1 inch to 14 inches or 3% to 36% of the annual rainfall, (Wischmeier, 1966). Both of these extremes occurred within a single soil textural group.

Musgrave (1955, pp 163), summarized the physical and management factors governing the intake rate of soils and their effects on runoff.

Runoff is frequently as small as 10% of the rainfall and on gentle slopes may move at velocities of 0.3 to 3 feet per second, compared to about 30 feet per second for rain drops, (Osborn, 1955, pp 126-134). On the Middle Branch of Westfield River, at Gass Heights, Mass., the average annual amount of intake is 19.6 inches or about 43% of the annual rainfall. Red River area at Fargo, N. Dak; absorbs 19.7 inches corresponding to 94% of the annual rainfall, whereas Pearl River at Edinburg, Miss., takes in 38.8 inches or nearly twice as much, but only 70% of the rainfall (Musgrave, 1955, pp 151-160). In some parts of the South of the U.S.A. the amount of runoff averages less than 0.01 inch, but there the rainfall is also low.

Runoff and Rainfall Parameters

Rainfall is one of the most important factors that affect the amount of runoff. Wischmeier (1966) found that there was a poor correlation between quantity of runoff and its soil content and concluded that the rainfall parameter that is most accurate for soil loss prediction i.e. the Erosion Index (E.I.) defined by the kinetic energy of a storm times its maximum 30 minute intensity (Wischmeier, 1958), is not also the most accurate one to account for runoff. He found that the computed kinetic energy of the storm alone was superior to the Erosion Index for the prediction of runoff independent of soil content, and after further exploratory analysis, found that momentum or rain depth times energy might serve as a runoff indicant.

Osborn (1955, pp 126-134), examined the effect of rainfall on runoff due to puddling and sealing of the soil surface by the impact of raindrops on bare soils and concluded that "the force of drops breaks down the loose crumbs at the surface. As the moisture penetrates the soil the cementing materials are softened and the aggregates disintegrate by slaking. Air may be trapped inside clods and aggregates in some soils. Pressures built up by compression of the air aid in breaking them down into individual particles. Soon a pasty mass is found on the surface. Water channels and pores are soon sealed by the fitting of small sized particles between the coarser ones and so an impervious layer is formed. Up to 2/3 of the energy of the falling drops may be used in ramming and compressing the surface soil and so these actions seal the expose land surface". He found that in tests with artificially applied rainfall, runoff from bare plots started 1 to 4 minutes from the commencement of application. As much as 95 to 98% of the applied water, even on sandy loams and sands, was lost as runoff.

Runoff and Physical Properties of Soil

Bertrand *et al.* (1964) in their studies on the effect of soil physical properties on runoff found that seven variables, six of which are soil separates, explained 89.5% of the variation. Runoff decreased with an increase in percentage of total sand but when sand was broken down into seven size classes, there was an increase in runoff with increase in percentage of coarse sand and fine sand but a decrease with increasing very coarse sand and very fine sand. There was also an increase in runoff with increase in percentage of material greater than 4760 u. It was found that a high percentage of material larger than very coarse sand increased runoff as do coarse and fine sand fractions. Runoff increased as the percentage of silt increased and $\log_e$ of percent silt was the best variable in the final equation for predicting runoff, having an exponential relationship. Runoff and percent clay were also exponentially related. The $\log_e$ of percent clay was the fourth variable in order of importance in the final runoff equation. As the ratio of clay to sand plus silt increased, runoff decreased. There was an increase linear relationship between runoff and 20 u suspension percentage, while there was an exponential relationship with the 50 u suspension percentage. As bulk density increased runoff increased at something less than a linear rate.

Wischmeier (1966) found that in a linear regression, silt content appeared to explain 42% of the total runoff variance among 40 soils tested, but the apparent correlation was due almost entirely to the high infiltration on four soils that were more than 75% sand. When those four soils were omitted from the regression, percent silt explained 10% of the runoff variance in the other 35 test. The 35 soils included 22 silt loams, 2 silty clay loams, 7 loams, and 4 sandy loams.

Runoff and Slope

In simulated rainfall tests Beutner et al. (1940) detected no significant effect of percentage slope on runoff on an essentially bare, non cultivated, gravelly, sandy loam soil. However, during eight years of continuous cotton on Cecil sandy loam in Georgia runoff from a 7% slope was 58% greater than from a 3% slope. On fallow land, runoff from different slope steepnesses approached equality as the soil surface became smooth, and the pervious surface layer approached saturation. In field plot rainulator tests on 21 fallowed silt loams and silty clay loams in Indiana, the effect of slope steepness on runoff from 2.5 inches of rain applied in one hour, was highly significant. Under a second 2.5 inch application 24 hours later, on the wet soil, slope effects on the same plots were substantially less. Wischmeier (1966) attributed the variability in the results of research workers (Hays, 1932; Neal, 1938; and Zinc, 1940) carrying out studies on slope runoff relations to the fact that they used different methods for surface preparation and application of water.

Under natural rain, runoff studies with several slope steepness on a common soil type were conducted in Wisconsin, New York, Virginia, Mississippi, Ohio, Illinois, Georgia, and Texas, (Wischmeier, 1966). In all the studies except that of Illinois, significant increase in runoff was observed from row crops with increases in slope steepness. In the illinois study, which appears to be an exception, significantly higher corn yields on the steeper slope evidenced a difference either in the soil or in past management.

With corn or cotton cover the slope-runoff relation was found to be curvilinear. Wischmeier (1966) found a positive linear relation between the logarithm of runoff and percent slope, this relationship was formulated as $\log W = 0.521 + 0.41 S$ in which W is inches of runoff and S is percent slope. Thus he found, within the slope range of data, a 10% average increase in runoff for each additional percent of slope for intertilled crops. On areas in small grain stubble, the relation of runoff to percent slope appears to be linear, but within 3% to 12% slope range the derived equation appears to be approximately correct also for these cover condition.

Zing (1940) found that slope length was of questionable significance as a factor in predicting long-time runoff from field areas. Wischmeier (1966) after studying the data from 21 slope length relations under natural rain over 12 states for an average of ten years, found that in 15 of these studies annual totals of runoff per unit area was not significantly related to plot length. He found that on 18 of the 21 studies, total growing season runoff per unit area was least on the longer slope, though the difference at some of these locations were not of significant magnitude. Only 2 of the 21 studies indicated a significant increase in runoff with increasing slope length. Duley and Acherman (1934) got similar results. During the growing season total runoff per unit area was found to increase with increases in slope length in 11 of the 31 studies indicating physical change of surface conditions. These results were on silt loam or fine sandy loam. In the ten studies that were on loams, clay loams silty clay loam, dormant season runoff either decreased with increasing slope length or was unaffected.

Runoff and Plant Cover

Vegetation is an important factor governing runoff. Wischmeier (1960) found that the ratio of runoff from crop land to corresponding runoff from adjacent fallow declined through the successive stages of crop development. He noticed that runoff reducing effectiveness of vegetal cover or minimum tillage diminishes when the pervious soil layer has become saturated.

Runoff from row crops averaged 12% of the total rainfall, while that from small grain and meadow averaged 9% and 7%, respectively (Wischmeier, 1966). Rye grass, oatgrass or a combination of vetch and rye as winter cover reduced the harvest to spring plow runoff by from 18% to 58%. The actual magnitude of these reductions averaged 0.5 inch per hour.

A crop cover study conducted at State College, Pennsylvania, 1940-45, indicated an overall 20% reduction in runoff by ryegrass or tall meadow oatgrass winter cover (Wischmeier, 1966). About 80% of the total runoff occurred in four major thaw periods in which runoff greatly exceeded precipitation. For these four periods, runoff from the vetch winter cover equalled that from the check plots. Other than in the four major thaw periods, the vetch and rye cover also effectively reduced runoff.

Runoff and Productivity Level

Productivity level also influences runoff significantly. Wischmeier, (1966) stated that in 25 years of plot studies runoff averaged 12% of the total precipitation; in the last ten years, with higher crop productivity levels resulting from improved fertility and management, it averaged 1% . Data from 50 plot years of continuous corn indicated a highly significant curvilinear and inverse relation between corn yields and surface runoff from the growing or maturing corn. He found further that for 35 soils with sand contents ranging from 4% to 66%, runoff was inversely proportional to organic matter content.

Soil Moisture

Soil moisture data are needed by farmers, agronomists, engineers, and hydrologists for studies of runoff from watersheds, the effect of the accumulation of moisture under pavements, the movement of moisture in the soil, the availability of moisture for plant use, the time and amount of irrigation, and many other problems (Haise, 1955, pp 362). There are various methods for measurement of soil moisture.

Direct Methods

Gravimetric methods of soil moisture measurement are the most common. The method of Gardner and Kirkham (1952) for example is to weigh the soil sample before and after oven drying i.e., when it has reached a constant weight. The loss in weight represents soil water as a percentage of dry soil. There are several disadvantages in the use of this method. It takes at least 24 hours to obtain results. Considerable labor, time and equipment are necessary to sample the soil, dry it, and make weighings (Haise, 1955, pp 362). Other disadvantages are due to the fact that, the soil sample is disturbed in the measuring process, and also continuous reading of the moisture at a point in the soil can not be made, (Gardner and Kirkham, 1952).

Indirect Methods

In these methods soil characteristics other than moisture are measured. Electric resistance is one of the indirect methods used, (Schwab, 1966, pp 136), and the most common of these is that of Bouyoucos developed in 1949. Other indirect methods are based on thermal conductivity, thermal diffusivity, dielectric constant, and soil moisture tension. In the indirect methods, calibrations are required and they are not dependent alone on the moisture content of the soil (Gardner, 1952). Some of the factors that may disturb calibrations are texture, temperature, electrical contact resistance, salt concentration, and time of reading. Time of reading causes trouble in methods in which a period of time is required for the soil moisture detector to come into equilibrium with the corresponding water.

The nuclear technique for soil measurements by neutron scattering which has been under development since 1950 is superior to all others. This method is more precise, much faster for a given reading and could be applied with substantially no disturbance to the strata involved. Stone et al. (1960) found that the neutron method of measuring soil moisture requires approximately one seventh of the sampling sites of the gravimetric method to have comparable accuracy.

There exists a definite relationship between the number of counted slowed down neutrons and percent moisture of the soil (Gardner and Kirkham, 1952), and (Stone, 1955).

Most authors agree that different mineral soils have the same calibration curve. The possible exception is in work reported by Mortier et al. (1956). He obtained one calibration curve for clay and another for loam and sand. The results of Stolzy and Cahoon (1957) confirm the use of one calibration curve. Stone et al. (1960) reported a S-shaped curve in a laboratory calibration.

Taylor (1955) obtained a linear relationship between neutron counts and water content of soil. Stone (1955) reported that the number of slow neutrons detected per unit time in organic soils is not necessarily a measure of soil moisture. Gardner and Kirkham (1952) showed that for maximum sensitivity the neutron source should be as near the detector tube as possible. Stone and Kirkham (1955) experimentally verified that the sensitivity is doubled by placing the source in the mid plane of the sensitive volume of the detector tube. Stolzy (1957) showed that steel tubing has one advantage over aluminium in that it can be driven into the soil with less damage. Lane et al. (1958) prepared calibration curves using both steel and aluminium access tubes and showed that slow neutron count was lower per unit of time with steel tubes than with aluminium. Stone et al. (1955) found that except for the surface 6 to 9 inches the equipment generally gave the soil moisture per unit soil bulk volume, within the range of the standard deviation of gravimetric determination and a single calibration curve served for all soil tested, i.e., sand silt loam, and silty clay loam. McHenry (1963) found that observed readings for Troxler-probe and Nuclear-Chicago probe were influenced by the material below the access tube if the probe is within 4 inches of the bottom of the tube. The presence of rocks or air spaces in the area about the neutron probe reduced the measured slow neutron flux. Lawless et al. (1963) found that neutron moisture probe readings taken near the soil surface underestimates the moisture content. The magnitudes of air-soil interface effects are related to the soil moisture content. The effect extends deepest in dry soil to as much as 18 inches or more. The absolute error is greatest in wet woil, where it may exceed one inch of moisture per foot. The neutron probe method is assumed to be temperature independent as long as the temperature is below 32°C. Hanbali (1964) reported that Davidson et al. found inaccurate probe readings when the temperature was above 32°C.

Evapotranspiration

Soil moisture status of soil can be predicted by the use of indirect procedures which are commonly used for the estimation of consumptive use (Robins et al., 1964). These indirect procedures can be grouped into the following categories:

Empirical formulae: These formulae are developed based on empirical relationships between evapotranspiration and one or more common climatic factors (Lloyd et al., 1966). Examples of this type of formulae are those of Thornthmaite (1948) and Blaney and Criddle (1950). These methods prove reliable for areas of climate similar to those in which they were derived, but generally are of limited use (Lloyd et al., 1966). The basic assumption in the above mentioned methods is proportionality of temperature to evaporation. Stork (1959) after comparison of actual net irrigation requirement from Dujailah experimental field to that of Blaney and Criddle, found that usefulness of this method is limited without determination of a monthly K factor for the areas concerned. He also mentioned that since Thornthwaite's formula does not have any crop coefficient in which other factors influencing evaporation can be included, no practical result can be drawn. Van Wijk and DeVries (1954) and Pruitt (1960) stated that predicted monthly values on the basis of Blaney and Criddle method are usually reliable, but for short periods error may be large, hence Robins (1965) concluded that use of this method for irrigation estimation is hazardous. Decker (1962) found that Thornthwaite's equation gave very precise estimates of evapotranspiration over larger periods, but produced inaccurate estimates when a shorter period was considered. Lloyd et al. (1966) stated that the inclusion of empirical terms in the formulae which only hold for a limited set of conditions and which are not applicable to widely varying conditions are the main limitations for their widespread use.

Turbulent Vapor-Transfer Method

The second approach for determination of evapotranspiration is based on the turbulent vapor-transfer theory. Examples of this type is that of Thornthwaite and Holzman (1942). Application of this method requires measurements of wind velocity and humidity at at least two elevations and is seldom practical (Schwab, 1966, pp 84). Sensitivity of instruments and adherence to boundary conditions are very critical in this method and because of these requirements they are not applicable except for very especialized measurements (Robins, 1965). Other descriptions and limitations of the methods based on this theory are given by Halstead and Covey (1957) and Tanner (1960).

Heat Budget Method

The third general method is "heat budget" or "energy balance" concept which has been described by Penman (1948, 1956). This method is based on disposition of energy at the land surface (Halstead and Covey, 1957; Levine, 1959; Tanner, 1960) and the concept of partitioning incident net radiation to the various processes in which it is consumed, namely evaporation of water, heating the soil, heating the air, and use in photosynthesis. Stork (1959) found that in general the Penman formula was in agreement with the empirical results of Dujailah experiment fields, however, he recommended more detailed work to be done on this subject in order to be able to use the formula for the determination of evapotranspiration. A problem associated with the use of Penman equation for consumptive use determination is the estimation of actual evaporation from the calculated potential evaporation. The evaporation figure produced by the Penman formula is the amount of water evaporated from a short green crop completely covering the ground and well supplied with water (Lloyd et al., 1966). This is similar to evaporation from most uniform green vegetation adequately supplied with water, or evaporation from wet soil. Penman (1948) stated that evaporation from a freshly wetted bare soil will be about 90% of that from an open water surface exposed to the same weather. He gave different factors for estimation of actual evaporation from potential evaporation from turf with a plentiful water supply in different season of the year. Penman and Schofield (1964) suggested from laboratory experiment that the evaporation rates from bare soils with a dry layer may be only 10% that of potential evaporation after the first 25 mm have evaporated. Lloyd et al. (1966) stated that in Pakistan it had been found that evaporation from bare soils fell almost to zero towards the end of the dry season, so this 10% rate must decrease further with time. In Jordan, during the period of early rain when the potential evaporation exceeds the rainfall, Lloyd et al. (1966) estimated the actual evaporation to be equal to rainfall plus 10% (potential evaporation-rainfall) provided that there was already some water stored in the soil to support this. Hutchinson et al. (1958) stated that an annual crop starting from bare soil and progressing to full cover departs from Penman's model of complete cover. They suggested a factor of 0.3 at planting to a factor of 1.4 at full cover should be applied to Penman's estimated potential evaporation. Decker (1962) found that Penman's method estimated the average daily evapotranspiration with considerable precision where the soil moisture was maintained at or near field capacity. Penman (1962) found that meteorological estimates of water use were in acceptable agreement with the values obtained by soil sampling.

Evaporative Devices

The fourth approach for the indirect estimation of evapotranspiration is the use of evaporative devices such as evaporation pans and atmometers. These methods have been suggested by Gray et al. (1955). Bouwer (1959) and Pruitt (1960). The basic principle underlying the use of these methods is the assumption that these devices will integrate the over all effect of the climatic factors influencing the evaporation which in turn is presumed to correlate with evapotranspiration by well watered vegetation. Robins (1965) stated that a good knowledge of the empirical relationship between evapotranspiration and evaporimeter measurements under conditions similar to those that prevail experimentally is a prerequisite for the proper estimation of evapotranspiration from these methods. Hearn (1964) studied the relationships between estimated evapotranspiration and evaporation as measured by an open pan and found that from July to November which is the dry season period the measured evaporation exceeded Penman's estimate by a steadily increasing ratio. As this difference was closely correlated with the actual value of the Penman's estimate, correlation between Penman's and Pan losses was good. From May to November the correlation for 10 day means gave a coefficient of determination of 0.9532. Stork (1959) after studying the values for evaporation from pans at experiment stations in Dujailah and comparing, these values with potential evaporation from Penman, criticized the use of a given factor e.g. 0.7 for estimation of evapotranspiration especially during the summer months, when the evaporation from the pan was large. He mentioned that few authors took into account the local characteristics of the relevant water surface compared, which is of great importance owing to the storage of heat, capacity, turbidity and its rate of mixing. These together determine the vertical extent of water which shares in the incoming energy supply during the day and which supplies outgoing energy at night. Lemon _et al._ (1957) stated that evapotranspiration is a function of soil, plant and meteorological factors. Attempts to predict evapotranspiration without considering all pertinent factors can meet only with qualified success. He added that evapotranspiration is controlled by soil moisture tension, physiological factors, the relation of soil moisture of an irrigated area to that of its surroundings as well as purely meteorological factors of radiation, wind, air temperature, and humidity.

III. MATERIALS AND METHODS

This study was conducted during the years 1966-67 and 1967-68 at the Agricultural Research and Education Center of the American University of Beirut situated 80 kilometers east of Beirut in the Beqa'a (latitude 33^{0} 55.50' and longitude 36^{0} 4.50'), Lebanon.

The average annual precipitation for the past 11-year period 1957-67 was 445.9 mm, and the distribution of the average precipitation was as follows:

Month/mm of rain: September, 2.5; October, 20.4; November, 40.3; December, 102.0; January, 103.2; February, 76.3; March, 63.3; April, 24.0; May, 13.2; June, 0.74; July, 0.0; August, 0.0.

The mean of minimum temperature over the same period was 0.8^{o}C in January and the mean maximum 32.57^{o}C in August. The extremes were -4.12^{o}C in January 1964, and 34^{o}C in August 1962.

The soil on which the experiment was conducted is a brown clay of sub-angular blocky structure, moderately developed in the upper horizons becoming more angular with depth and tending to prismatic structure with broken fine cutans. Generally hard when dry and sticky and plastic when wet, slight scatter of distinct black stainings, becoming slightly calcareous with encrustations on pebbles and stones. Rounded stones at the surface with occasional scattered stones throughout the profile, well drained. Majdaloun Series; Sub-tropical Chestnut (Vertic Argixeroll).

The detailed profile description is:

0 - 25 cm; stony (rounded), 7.5 YR 4/4 (moist) clay; fine granular structure, slightly hard, slightly calcareous. Boundary gradual and smooth.

25 - 60 cm; 7.5 YR 4 or 5/4 (moist, clay, moderate, medium subangular blocky; hard when dry, very sticky when wet; occasional black staining; slightly calcareous. Boundary gradual and smooth.

60 - 80 cm; 7.5 YR 4/4 (moist) clay; strong angular blocky structure tending to prismatic with thin broken cutans; very hard when dry, very sticky and plastic when wet; fine distinct black nodules, faint, diffuse reddish yellow mottles. Slightly calcareous. Boundary gradual and smooth.

80 - 130 cm; 7.5 YR 5/6 (moist) clay; strong angular blocky; hard when dry, slightly plastic when wet. Calcareous.

Variant: Discontinuous stone line of varying thickness. Very stony in matrix of strong, medium subangular blocky clay between 40 and 90 cm-depths.

The soil has an average bulk density of 1.3 g/cc determined by using a core sampler. At field capacity the top one meter of soil contains 266 mm of water determined by application of 1/3 atmosphere, (Richard and Weaver, 1944). The water content of the top meter of the soil at permanent wilting point is 170 mm determined by application of 15 atmosphere (Richard and Weaver, 1943).

Plot Layout and Management

Nine runoff plots were established in October 1966. All plots were 6.66 meters wide, six of these were 200 square meters and the other three were twice as large. Three different slopes, two slope length and a rotation of wheat, fallow and vetch were the treatments applied to these plots. The same treatments were repeated for the year 1967-68, except that the wheat and vetch plots were interchanged. The specific treatments for each plot are shown in Table 1.

Planting for the year 1966-67 was done in late November and for the second year on November 15. The wheat crop germinated a week after sowing, while the vetch took three weeks. All plots received the normal cultural treatments practiced in the area, i.e. nitrogen was added in the form of ammonium sulphate at the rate of 8 kg per dunum and phosphorous (P_2O_5) was applied at the rate of 8 kg per dunum. Tillage operations were done on fallow plots in February. Later weeding was done by hand as required. The wheat plots were top dressed in early March in both years.

Determination of Erosion Index (E.I.)

Erosion Index, a parameter of rainfall whose relationship with runoff has been under study in this work, is defined as the product of total kinetic energy of a storm and its maximum 30 minute intensity, Wischmeier (1958). Kinetic energy is the energy due to motion and is equal to half of the product of the mass and square of the velocity or $E_K = 1/2\ m\ V^2$. The kinetic energy producing potential of a rain is a function of size, shape, and distribution of drop sizes. Distribution of drop size is related to intensity by the formula $D_{50} = 2.23\ I^{0.182}$

Table 1. Runoff plots and their corresponding treatments for the two years 1966-67 and 1967-68.

Treatment Plot number	Percent slope	Length of slope meters	Crop 1966-67	Crop 1967-68
1	2.5	30	Wheat	Vetch
2	2.5	30	Fallow	Fallow
3	2.5	30	Vetch	Wheat
4	4.5	30	Wheat	Vetch
5	4.5	30	Fallow	Fallow
6	4.5	30	Vetch	Wheat
7	3.5	60	Wheat	Vetch
8	3.5	60	Fallow	Fallow
9	3.5	60	Vetch	Wheat

in which D is in inches and I in inches per hour.

A single storm has to be defined, before its kinetic energy is determined. The optimum minimum time to define as the break between storms is a function of the changes in infiltration rate after cessation of a rain and it varies with soil type. A time difference of 6 hours is generally accepted as the best for seperation of rain storms (Wischmeier, 1958). The routine procedure for obtaining a measure of the total kinetic energy (K.E.) imparted by the countless raindrops comprising a storm is by the use of correlation of drop size distribution with intensity. Intensity in turn is correlated with K.E. by the following equation derived by Wischmeier (1950): $K.E. = 916 + 331 \log I$, expressing K.E. in foot tons per acre inch as a function of intensity of rainfall in inches per hour. A table has been worked out based on this formula (Appendix 1). By point analysis of recording raingauge charts, a tabular record of intensities with the amount of rain falling in each phase of intensity is made. The corresponding energy figures from the table multiplied by the inches of rain falling at this rate describes the energy value of the increment of the storm. These partial products are accumulated to obtain the total energy value of the storm. The maximum 30 minute intensity is obtained from the rainfall chart and the product of these two gives the Erosion Index (E.I.) of a single storm.

Runoff Measurement

Runoff measurements were made after each rainfall as time permitted. Runoff was collected into reception tanks laid in dugtrenches. The measurements were made volumetrically, i.e. by measuring the depth of water in the tanks knowing the area of each of the plots and the area of the corresponding tank, the depth of runoff from each plot was determined. The assumption was made that contribution of rain water to these tanks and evaporation loss from them are compensating and equal for each tank. After each runoff measurement the tanks were emptied.

Soil Moisture Measurement

A neutron scattering probe and recorder was used for measurement of soil moisture. Two steel tubes were set in each of the short plots and three in each of the long ones, to a depth of one meter. Moisture measurements were made at two depths, 25 cm and 75 cm and these readings were taken to represent average soil moisture content in the first 50 cm depth and second 50 cm depth, respectively. On each occasion two readings were made at each station and since there were seven stations for each crop, therefore, the measurement at each depth for each crop at each date was the average of 14 readings.

Soil moisture measurements were started in May 1967. By means of soil moisture measurements changes in soil moisture content due to rainfall, evapotranspiration, and deep percolation were calculated.

To estimate the amount of deep percolation and evapotranspiration during rainy periods, the Penman equation, modified by Black et al. (1955) and reviewed by Lloyd et al. (1966) (Appendix 2) was used to determine potential evapotranspiration. An average reflection coefficient of 25% was assumed for wheat and vetch and 20% for bare soil as suggested by Lloyd et al. (1966).

The actual evapotranspiration for the period of October 30 to December 5 was assumed to be 50% of Penman potential figures. This assumption was made after comparing soil moisture status during this interval with that during the month of April, when direct soil moisture measurement gave a factor of 0.7 for conversion of Penman potential values to actual evapotranspiration.

For the period of December 5 to April 3, when the soil moisture was at or near field capacity, the actual evapotranspiration was assumed to be equal to potential values. This assumption was based on the fact that potential evapotranspiration values produced by Penman formula are based on the amount of water evaporated from a short green vegetation adequately supplied with water.

Analysis of Results

To analyze the effect of different factors on runoff, a computer program for the application of principles of multiple correlation analysis was prepared. The multiple correlation coefficients between the independent variables and runoff are presented in the following chapter. The independent variables considered for the first year were: percent slope, length of slope, crop factor, Erosion Index, and kinetic energy.

Crop factors were derived by taking average runoff from fallow plots in each period as a base and giving it a value of 1. The wheat and vetch crop factors were consequently the ratios of average runoff from wheat plots and vetch plots to that of fallow plots.

Under the rainfall energies experienced in the first season, the crop factor showed no effect and consequently, for the second year the crop factor was not considered and the independent variables used for the analysis were percent slope, length of slope, Erosion Index, kinetic energy and rain depth.

Daily potential evapotranspiration values were calculated by preparing a computer program and using the climatic data from the weather station at A.R.E.C.

IV. RESULTS AND DISCUSSION

Runoff

The total amount of runoff during the year 1966-67 ranged from 8.67 mm or 1.47% of the total precipitation from the vetch plots on 3.5% slope and 60 meter long to 23.58 mm or 3.99% of the total precipitation, from the fallow plot on 2.5% slope and 30 meter long (Table 2, Figure 1). The corresponding range of values for the year 1967-68 were 8.70 mm to 21.21 mm or 1.58 to 3.83% of the total recorded precipitation from the same plots (Table 3, Figure 1).

Comparing these runoff values with those reported by Wischmeier (1966), as being 1 inch to 14 inches or 3% to 36% of annual precipitation, the runoff under the experimental conditions were very small. The relatively low values of runoff from the erosion plots can be explained by the fact that the individual Erosion Index values experienced, which are indicators of erosion, (Wischmeier, 1958), and from these studies also runoff producing capacity of a rainstorm are low, i.e. the total value for year 1966-67 was 27.08 (Table 4) and that of 1967-68 was 48.12 (Table 5) while the values reported for areas of erosion expectation, would range from 100 to 300 and more. The maximum E.I. value (Table 4) from any individual period of rain during the year 1966-67 was 7.92 (December 19 to 24) and the minimum was 0.64 (December 1 to 5). For the second year of experiment (Table 5) the corresponding values were 13.41 (November 1 to 7) and

Table 2. Depth of runoff per unit area from erosion plots in 1966-67. (millimeters)

Dates of measurement \ Plot No.	1	2	3	4	5	6	7	8	9	Total	Average
December 5	0.42	0.45	0.45	0.43	0.40	0.32	0.20	0.16	0.18	3.01	0.33
December 12	1.10	2.20	0.86	0.99	0.98	0.74	0.47	0.41	0.40	8.15	0.90
December 19	3.58	4.73	3.82	4.05	4.49	1.90	1.92	2.77	1.26	28.52	3.17
December 24	2.35	3.44	2.66	3.64	3.16	3.51	1.68	1.82	1.29	23.55	2.61
January 5	0.53	1.04	0.62	0.97	1.10	0.91	0.64	0.76	0.27	6.84	0.76
January 19	2.43	3.54	2.76	3.16	3.65	3.65	1.71	1.83	1.35	24.08	2.67
February 2	2.79	3.65	3.01	3.65	4.12	3.94	2.00	2.06	1.46	26.68	2.96
February 23	0.73	0.57	0.55	0.76	0.46	0.72	0.36	0.31	0.38	4.84	0.54
March 9	0.52	0.53	0.34	0.59	0.45	0.51	0.27	0.20	0.28	3.69	0.41
March 21	0.96	0.98	1.35	1.06	0.90	0.96	0.49	0.51	0.53	7.74	0.86
March 30	2.30	2.45	1.42	2.52	2.26	2.37	1.20	1.07	1.27	16.86	1.87
Total	17.71	23.58	17.84	21.82	21.97	19.53	10.94	11.90	8.67		

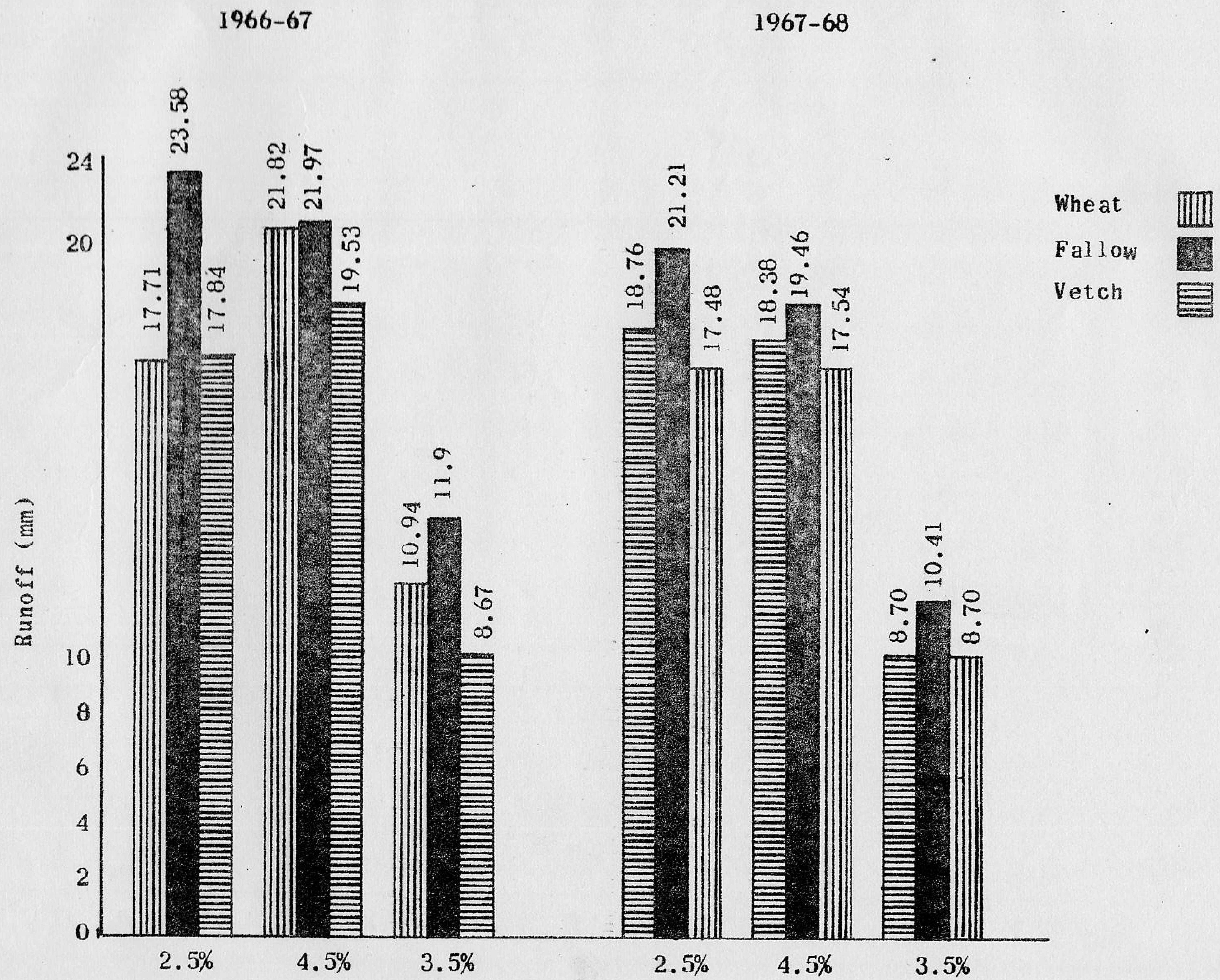

Figure 1. Histograms of total runoff from erosion plots during 1966-67 and 1967-68.

Table 3. Depth of runoff per unit area from erosion plots in 1967-68. (millimeters)

Dates of measurement / Plot No.	1	2	3	4	5	6	7	8	9	Total	Average
November 7	1.58	1.91	1.50	1.09	1.37	0.95	0.55	0.83	0.65	10.43	1.16
December 18	1.19	0.76	1.16	1.16	1.07	1.02	0.54	0.34	0.57	7.81	0.87
December 28	1.42	1.24	1.42	1.40	1.20	1.26	0.64	0.47	0.62	9.67	1.07
January 3	0.60	0.54	0.60	0.48	0.57	0.52	0.28	0.20	0.28	4.07	0.45
January 9	1.23	0.84	1.20	1.15	1.15	1.18	0.62	0.61	0.37	8.35	0.93
January 23	5.20	3.86	4.72	4.64	3.34	4.75	2.06	2.58	2.22	33.37	3.70
February 5	1.20	1.85	1.76	1.76	1.97	1.90	0.92	1.06	0.92	13.34	1.48
February 13	2.80	2.99	2.28	2.94	2.90	3.14	1.56	1.08	1.57	21.26	2.36
February 22	0.78	0.76	0.63	0.85	0.76	0.67	0.33	0.24	0.30	5.32	0.59
March 27	1.14	1.17	0.95	1.24	1.10	0.95	0.50	0.31	0.50	6.72	0.75
May 22	1.29	5.05	1.00	1.43	3.67	1.10	0.57	2.52	0.57	17.20	1.91
May 26	0.33	0.24	0.26	0.24	0.36	0.10	0.13	0.17	0.13	1.96	0.22
Total	18.76	21.21	17.48	18.38	19.46	17.54	8.70	10.41	8.70		

Table 4. Cumulative precipitation, kinetic energy, Erosion Index and runoff[x] for year 1966-67.

Dates of runoff measurement	Rainfall in mm	Kinetic energy foot ton/acre	Erosion Index foot ton/acre	Runoff in mm
December 5	21.9	269.20	0.64	0.33
December 12	69.0	726.51	1.90	1.23
December 19	112.4	1432.79	3.52	4.40
December 24	180.4	2841.81	11.44	7.01
January 5	198.8	3193.91	12.83	7.77
January 19	263.3	4565.31	16.93	10.44
February 2	349.4	6012.41	20.92	13.40
February 23	420.2	6596.31	22.15	13.94
March 9	471.0	7298.98	23.41	14.35
March 21	510.5	8140.51	25.08	15.21
March 30	590.3	9298.12	27.08	17.08

x. Average runoff from all nine plots for each date of measurement.

Table 5. Cumulative precipitation, kinetic energy, Erosion Index and runoff[x] for year 1967-68.

Dates of runoff measurement	Rainfall in mm	Kinetic energy X depth foot ton/acre	Erosion Index	Runoff in mm
November 7	92.9	2257.87	13.41	1.16
December 18	184.4	4248.27	17.77	2.03
December 28	218.4	5002.63	19.41	3.10
January 3	241.4	5206.45	19.98	3.45
January 9	266.4	5729.16	21.29	4.38
January 23	376.4	7703.96	25.12	8.08
February 5	425.9	8739.18	27.56	9.56
February 13	432.9	8914.00	27.85	11.92
February 22	469.9	9610.72	30.14	12.51
March 27	497.1	10012.60	31.10	13.26
May 22	529.1	11753.60	42.82	15.17
May 26	550.1	13262.60	48.12	15.39

x. Average depth of runoff from all nine plots for each date of measurement.

0.92 (February 5 to 13). Each E.I. value for any period corresponding to a runoff measurement is the summation of E.I. values for all the individual storms occurring during that period, and the E.I. values of single storms were often lower than those for the whole period.

The second contributing factor to the low runoff values is probably that the percent slopes on which the plots were laid (2.5, 3.5, and 4.5) were small while with those on which appreciable runoff were reported by research workers in U.S. (Wischmeier, 1966) are much higher.

The average runoff values from all plots for any period of measurement during the first year of the experiment ranged from a low of 0.33 mm measured on December 5 to a high of 3.17 mm measured on December 19, 1966 (Table 2). The corresponding range for the second year was 0.22 mm measured on May 26 to 3.7 mm measured on January 23 (Table 3). Seasonal variation of rainfall characteristics i.e., distribution, depth, and energy account for variation in time of occurrence of runoff.

Runoff and Slope

The table of the cumulative runoff values for plots with different percent slope and length of slope for the year 1966-67 (Table 6) shows that the average value for runoff from all plots on 4.5% slope was greater by 1.39 mm or 7.06% than plots laid on 2.5% slope. This order was reversed in the second season, i.e., the total average runoff from plots on 2.5% slope was greater than that of 4.5% slope by 0.99 mm or 5.31% (Table 7). The correlation between percent slope and length of slope

Table 6. Cumulative runoff[x] for plots with different percent slopes and slope length, 1966-67.

Dates of measurements	Percent slope / Slope length	2.5 30 m	4.5 30 m	3.5 60 m
December 5		0.43	0.38	0.17
December 12		1.83	1.28	0.60
December 19		5.87	4.48	2.58
December 24		8.69	8.20	4.18
January 5		9.42	9.20	4.73
January 19		12.33	12.68	6.37
February 2		15.48	16.59	8.21
February 23		16.10	17.23	8.45
March 9		16.57	17.75	8.70
March 21		17.66	18.73	9.21
March 30		19.72	21.11	10.40

x. Average of three runoff values from plots with the same percent and different crop cover.

Table 7. Cumulative runoff[x] for plots with different percent slope and slope-length, 1967-68.

Dates of measurements	Percent slope / Slope length	2.5 / 30 m	4.5 / 30 m	3.5 / 60 m
November 7		1.66	1.14	0.86
December 18		2.70	2.22	1.16
December 28		4.06	3.51	1.74
January 3		4.64	4.03	1.99
January 9		5.73	5.19	2.52
January 23		10.32	9.43	4.81
February 5		11.42	11.31	5.78
February 13		14.61	14.30	7.18
February 22		15.33	15.06	7.47
March 27		16.75	16.16	7.91
May 22		19.19	18.23	9.13
May 26		19.45	18.46	9.27

x. Average of three runoff values from plots with the same percent slope and different crop cover.

was 0.04 for the first year of experiment and 0.01 for the second year (Table 8).

Increasing percent slope from 2.5% to 4.5% does not, therefore, under low E.I. values affect the amount of runoff. This is due to the fact that the increment increase of percent slope over the range 2.5 to 4.5 is not large enough to result in substantial differences in runoff.

Research workers; Beutner et al. (1940), Borst et al. (1940), Neat et al. (1948), Wischmeier (1966) studying the effect of slope have in most instances shown significant increases in erosion and runoff. However, in some cases there have been inconsistencies and these have been explained by differences in rainfall and surface conditions (Wischmeier, 1966). Beutner et al. (1940) detected no significant effect of slope on runoff with sprinkler-applied precipitation on essentially bare, newly cultivated, gravelly, sandy loam soil. He found, however, that runoff from cotton on Cecil sandy loam soil on a 7% slope was 58% greater than from 3% slope.

The effect of length of slope on the amount of runoff is observed by comparing tables 6 and 7, and figures 2 and 3 of cumulative runoff from plots with 30 meter length and that with 60 meter length. Runoff values per unit area from long plots are almost half of those of short plots. The simple correlation coefficients between runoff and length of slope were 0.34 and 0.36 for the first and second year, respectively (Table 8).

Wischmeier (1966) reported that length of slope is probably of

Table 8. Simple and multiple correlation coefficients between runoff and independent variables, 1966-67 and 1967-68.

1966-67			1967-68		
X_1	Erosion Index	.5544	X_1	Erosion Index	.7083
X_2	Percent slope	.0416	X_2	Percent slope	.0100
X_3	Length of slope	.3431	X_3	Length of slope	.3698
X_4	Crop factor	.1327	X_4	Kinetic energy	.5920
X_5	Kinetic energy	.5342	X_5	Raindepth	.2507
X_1 X_2		.5560	X_1 X_2 X_3 X_4		.8256
X_1 X_3		.6520	X_1 X_2 X_4 X_5		.7499
X_1 X_4		.5637	X_2 X_3 X_4 X_5		.7054
X_2 X_3		.3456	X_1 X_3 X_4 X_5		.8361
X_2 X_4		.1391	X_1 X_2 X_3 X_5		.7977
X_3 X_4		.3679	X_1 X_2 X_3 X_4 X_5		.8361
X_1 X_2 X_3		.6525			
X_1 X_2 X_4		.5612			
X_1 X_3 X_4		.6596			
X_2 X_3 X_4		.4121			
X_1 X_2 X_3 X_4		.6613			

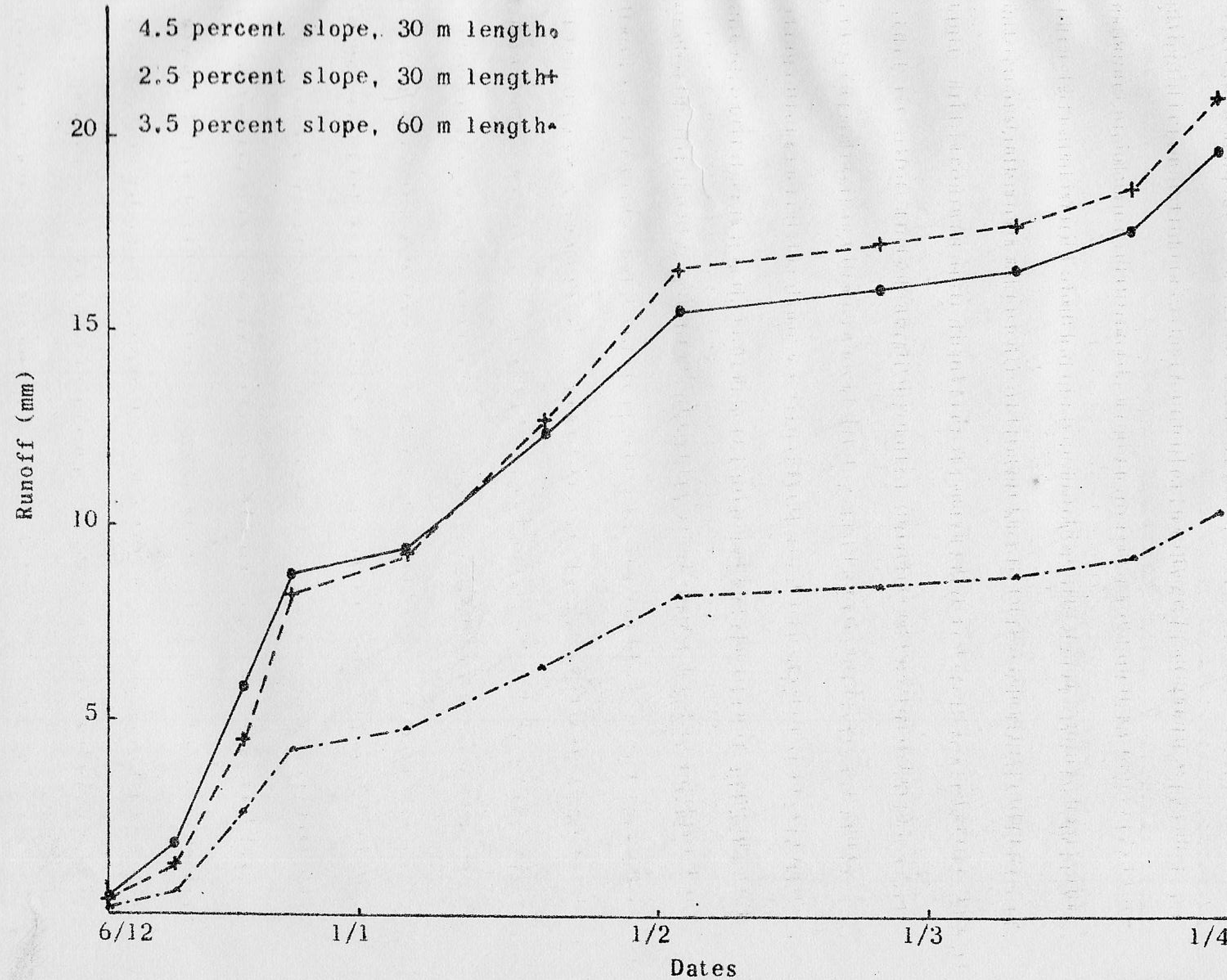

Figure 2. Cumulative runoff from plots with different percent slope and slope length. 1966-67.

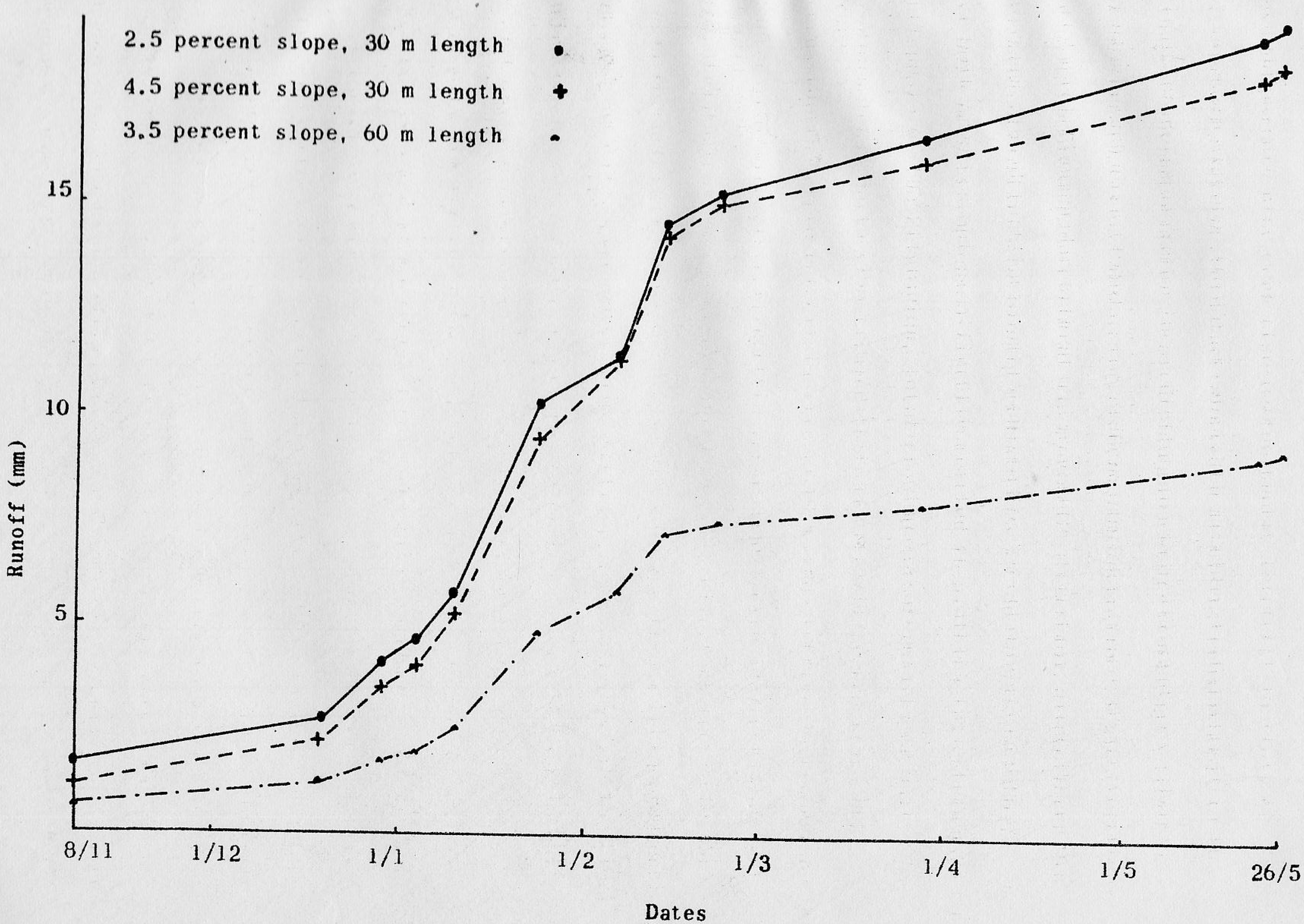

Figure 3. Cumulative runoff from plots with different percent slope and slope length. 1967-68.

questionable significance as a factor in predicting long-time runoff from field areas. The runoff of 21 studies showed that in 18 cases the total growing season runoff per unit area was least on longer plots.

Runoff and Plant Cover

The effect of plant cover on runoff is shown in Tables 9 and 10, and Figures 4 and 5. During the first year the curve of cumulative runoff from fallow plots is above that of wheat, and that from wheat plots is above that from vetch plots over the whole season, the average of the total runoff from fallow plots was 2.35 mm or 13.09% greater than that from wheat and that from wheat was 1.5 mm or 9.83% greater than that of vetch. In the second year the curves of cumulative runoff are almost the same until March 27, i.e., total runoff is 13.51 mm from wheat, 13.03 from fallow, and 13.93 from vetch. A single high intensity storm on May 22, however, resulted in a relatively higher amount of runoff from fallow plots compared with those from wheat and vetch. The runoff from the fallow plot on 2.5% slope and 30 m long for this storm was 5.05 m, which is the highest individual value of runoff observed during the two years, and this was about 16% of the total recorded rainfall for that storm. The average runoff from wheat, fallow and vetch plots were 0.89 mm, 3.76 mm, and 1.07 mm, respectively, for this storm.

Over the whole season there was no decrease in runoff from cropped plots as compared with fallow, i.e. over the period of December 5 to March 30 (1966-67). During this period temperatures dropped and remained below those required for active growth and there

Table 9. Cumulative runoff[x] for wheat, fallow and vetch, 1967-68.

Dates of measurements / Crop cover	Wheat	Fallow	Vetch
November 7	1.03	1.37	1.07
December 18	1.95	2.09	2.03
December 28	3.05	3.06	3.18
January 3	3.52	3.50	3.63
January 9	4.44	4.37	4.63
January 23	8.32	4.63	8.60
February 5	9.85	9.26	9.89
February 13	12.18	11.58	12.32
February 22	12.71	12.17	12.97
March 27	13.51	13.03	13.93
May 22	14.40	16.77	15.03
May 26	14.56	17.03	15.26

x. Average of three runoff values from plots with the same crop treatment and different slopes.

Table 10. Cumulative runoff[x] for wheat, fallow and vetch. 1966-67.

Dates of measurements / Crop cover	Wheat	Fallow	Vetch
December 5	0.35	0.37	0.31
December 12	1.20	1.56	0.98
December 19	4.39	5.56	3.31
December 24	6.94	8.37	5.80
January 5	7.66	9.34	6.39
January 19	10.10	12.35	8.98
February 2	12.91	15.62	11.78
February 23	13.53	16.07	12.33
March 9	13.99	16.40	12.71
March 21	14.83	17.26	13.66
March 30	16.84	19.19	15.34

x. Average of three runoff values from plots with the same crop treatment and different slopes.

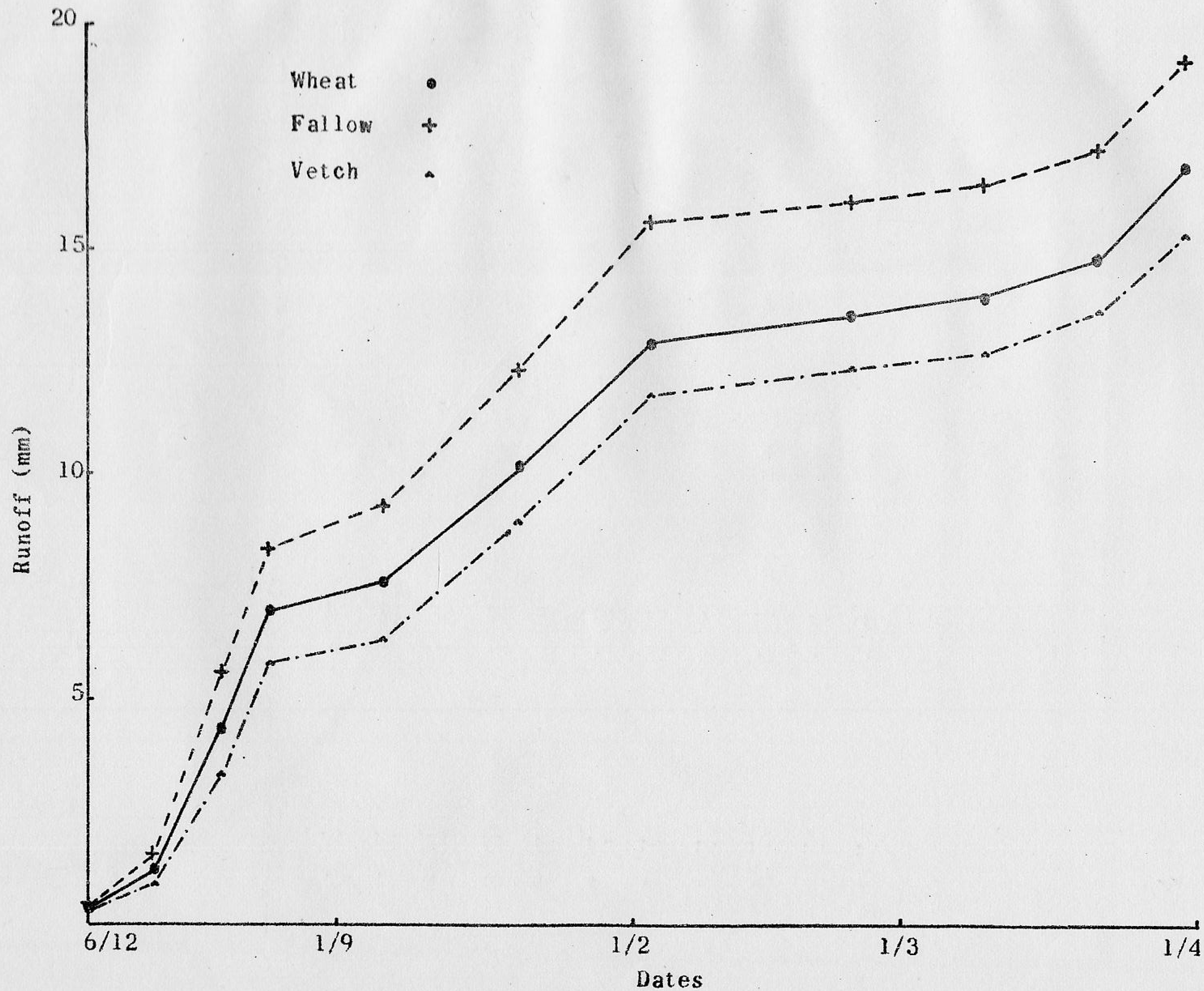

Figure 4. Cumulative runoff from wheat, fallow and vetch plots. 1966-67

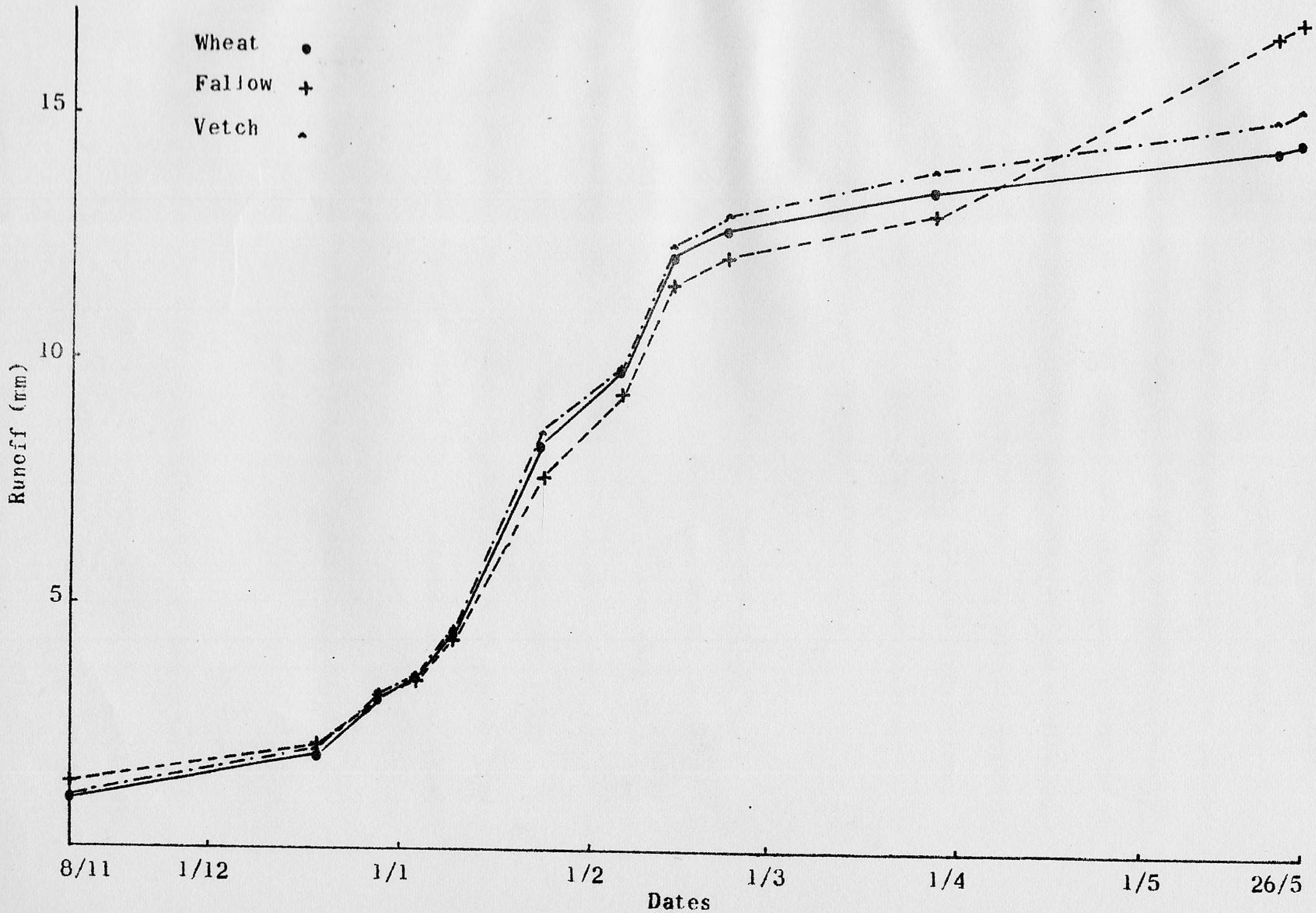

Figure 5. Cumulative runoff from wheat, fallow and vetch, 1967-68.

was inadequate crop coverage. There were some tillage operations during the month of February on the fallow plots for weed control and this disturbance of the surface soil resulted in higher infiltration rate of the rain water and consequently higher values of runoff from wheat and vetch (Table 11). The correlation between mm of runoff and crop factor was .1327 which shows that runoff is little affected by crop factors under these experimental conditions.

These results differ from those reported by various workers, exampled by Osborn (1962) who found that the ratio of runoff from cropland to corresponding runoff from adjacent fallow declined through the successive stages of crop development.

Runoff and Rainfall Parameters

The amount of rain; kinetic energy and Erosion Index for the two years are given in Tables 4 and 5. A comparison of the total values of each single factor for the two years shows that although the amount of rainfall during the first year (1966-67) was greater than that of the second year by almost 40 mm or 8% , the total Erosion Index for the second year was greater than that of the first yearly 78%. The total kinetic energy for the second year was also greater than that of the first year by 42%.

These apparent inconsistencies of different rainfall characteristics are partially explained by the high intensity values of the last two storms during May 1968, which raised the Erosion Index value for the year by 17 units or about 35% of the annual value, and raised kinetic energy values by 24% , while rain depth was raised by only 11% of the total precipitation. The high E.I. value of

Table 11. Crop factor values corresponding to each runoff measurement. 1966-67.

Dates / Crops	Wheat	Fallow	Vetch
December 5	1.04	1.0	0.94
December 12	0.71	1.0	0.56
December 19	0.78	1.0	0.58
December 24	0.91	1.0	0.88
January 5	0.74	1.0	0.61
January 19	0.81	1.0	0.86
February 2	0.86	1.0	0.86
February 23	1.40	1.0	1.2
March 9	1.16	1.0	0.95
March 21	1.05	1.0	1.19
March 30	1.04	1.0	0.87

these storms also accounted for the considerable erosion which occurred with runoff during that storm.

The relation of these rainfall parameters with corresponding runoff values during each period in each year is shown by simple and multiple correlation coefficients (Table 8) between runoff and these rainfall factors. The relatively high dependence of runoff on Erosion Index in comparison with rain depth or kinetic energy alone is apparent for the second year i.e. coefficients of 0.7 between E.I. and runoff, .25 between rain depth and runoff and 0.59 between kinetic energy and runoff. For the first year the correlation coefficients between runoff and E.I. was .55 and between runoff and kinetic energy .53 implying no significant difference between these two factors in influencing runoff for that year. Considering the results of the two years, it is concluded that Erosion Index is most closely related to runoff and rain depth the least.

Wischmeier (1966) stated that while Erosion Index reflects the influence of rain storm characteristics on soil concentration in runoff as well as infiltration and hence runoff, no positive universal relationship has yet been established, and he suggested that K.E. X rain depth might be superior to E.I. as an indicant, but neither of these two factors has consistently ranked first for all locational sets of data.

Analysis of Runoff Data

The multiple and simple correlation coefficients between runoff and independent variables are given in Table 8. For the first year the multiple correlation coefficient was .66 when combination of

Erosion Index, percent slope, length of slope and crop factor (x_1, x_2, x_3, x_4) were considered. However, considering Erosion Index and length of slope alone (x_1, x_3) the correlation coefficient was .56.

For the second year the multiple correlation coefficient was 0.83 when Erosion Index, kinetic energy, rain depth, percent slope and length of slope (x_1, x_2, x_3, x_4, x_5) were used together. Considering the correlation coefficients between runoff and any other combination of these variables, it is concluded that dependence of runoff on these factors decreases in the following order: Erosion Index; kinetic energy; length of slope; rain depth; crop factor; and percent slope.

Soil Moisture and Consumptive Use

Soil Moisture

Changes in soil moisture content in two depths of measurement during the periods October 30 to June 6, 1967-68 and May 4 to June 1, 1967 are given in figures 6, 7, 8, and 9. On October 30, 1967, moisture content of the fallow plots in the top 50 cm was about 110 mm or 12.02% greater than those being planted to wheat (94 mm) and 26.43% greater than the prospective vetch plots (87 mm). The available moisture at this depth on fallow, wheat and vetch plots were 25 mm, 9 mm, and 2 mm or 52%, 16.66%, and 4.16% of the total available water, respectively. In the second depth the moisture content was the same for the three treatments, being 120 mm i.e., 9.77% below the field capacity.

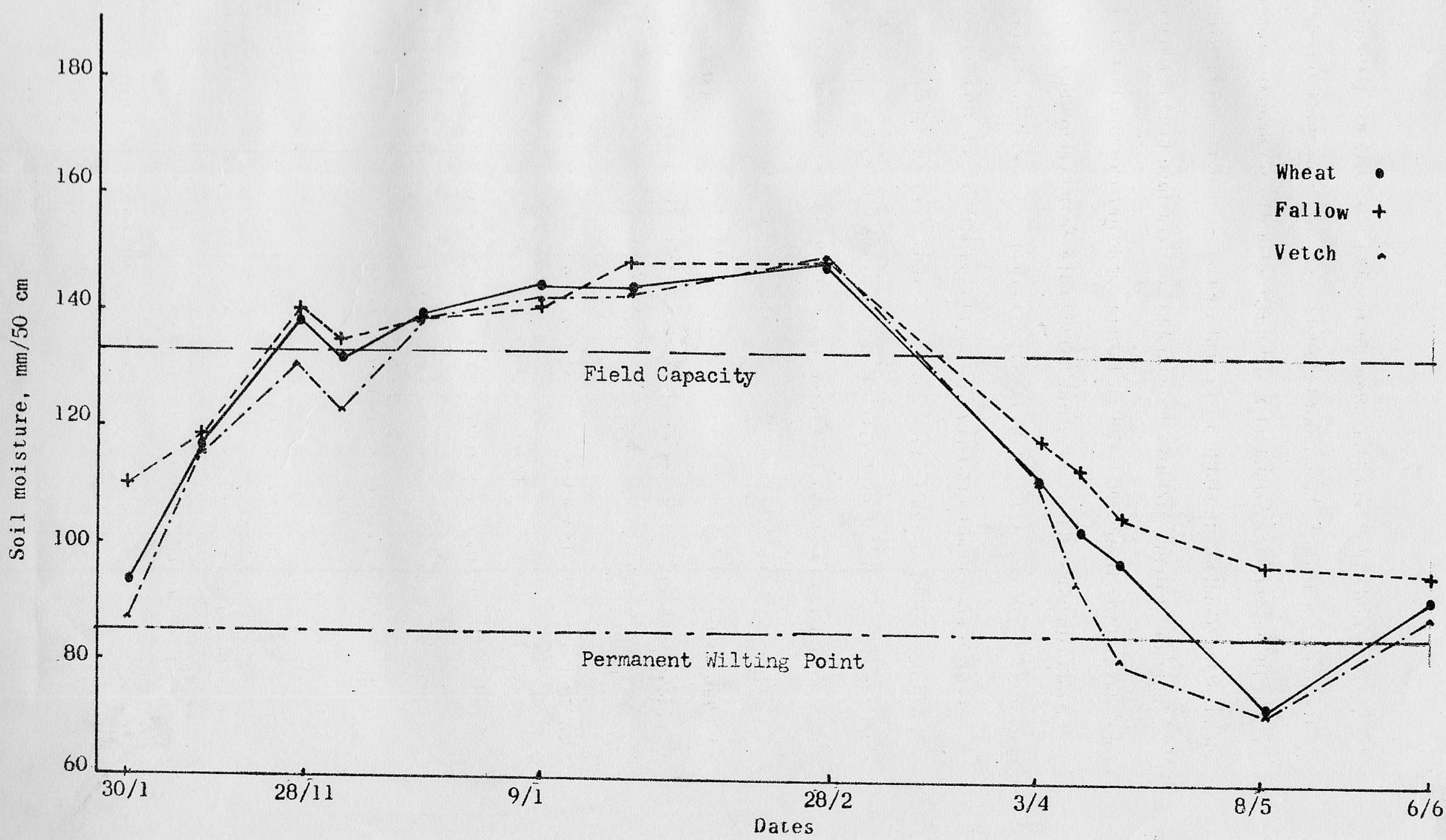

Figure 6. Soil moisture content in top 50 cm under wheat, fallow and vetch. 1967-68.

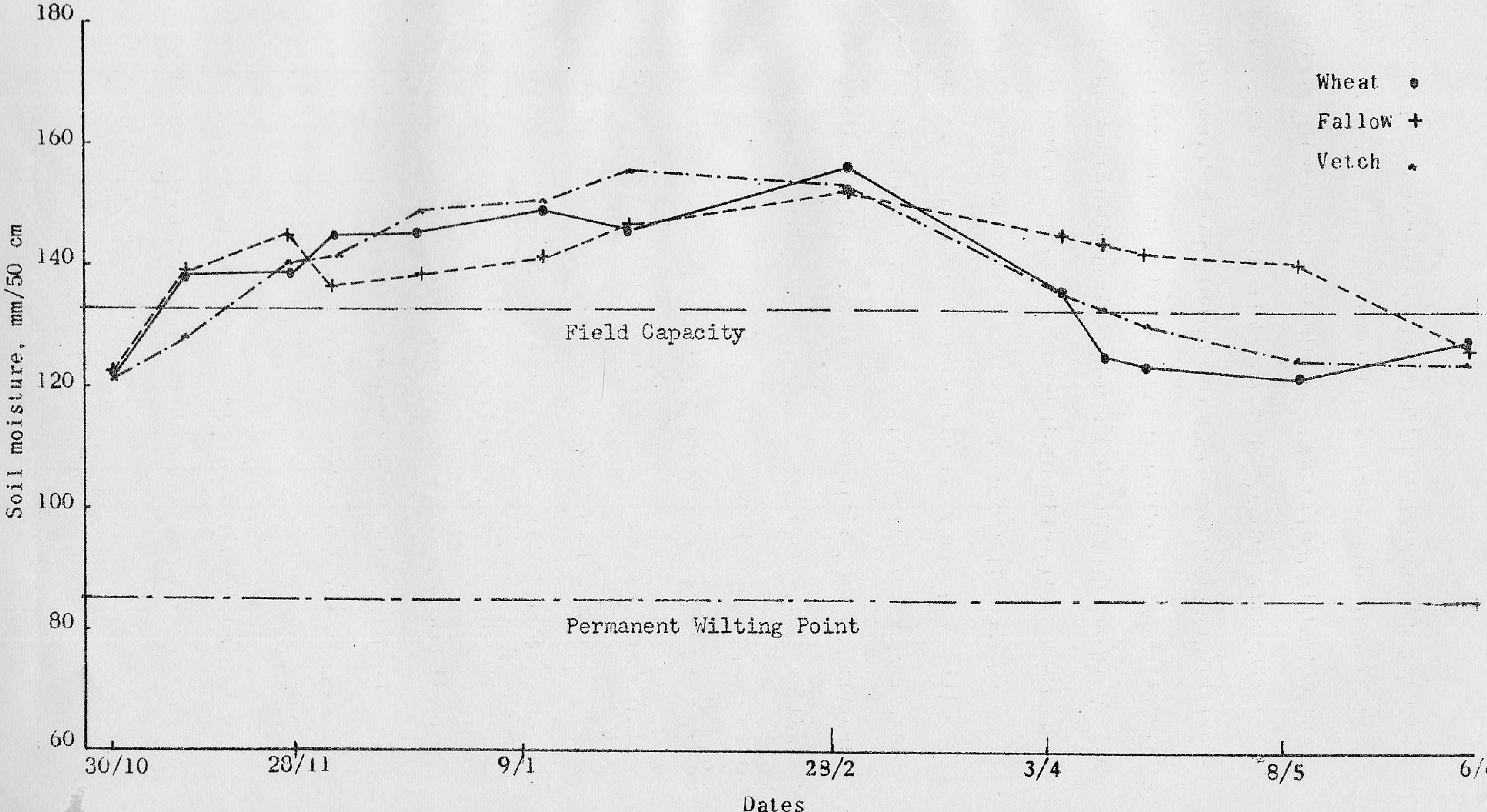

Figure 7. Soil moisture content in the bottom 50 cm depth under wheat, fallow and vetch, 1967-68.

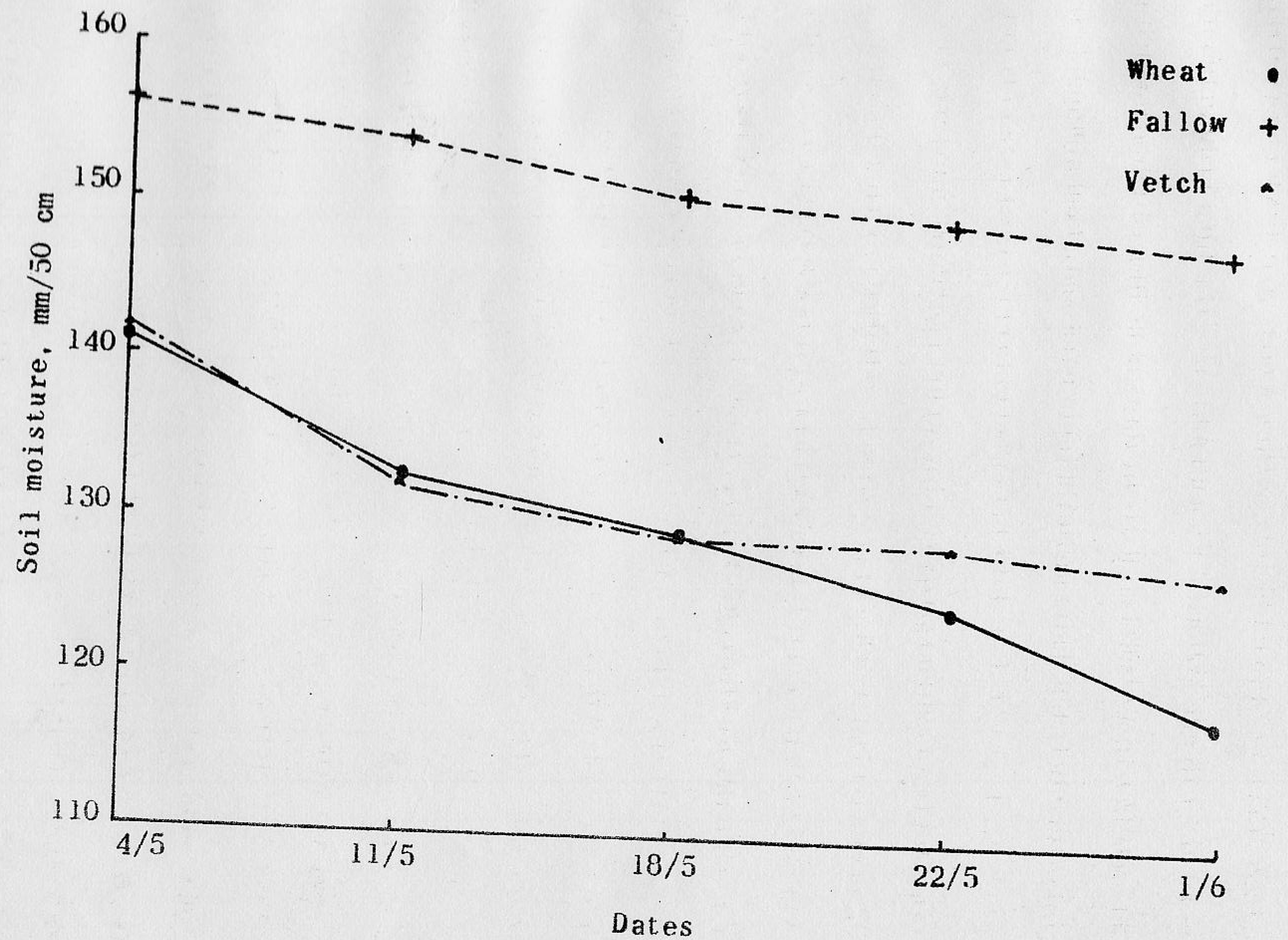

Figure 8. Soil moisture content in bottom 50 cm under wheat, fallow and vetch. May 1967.

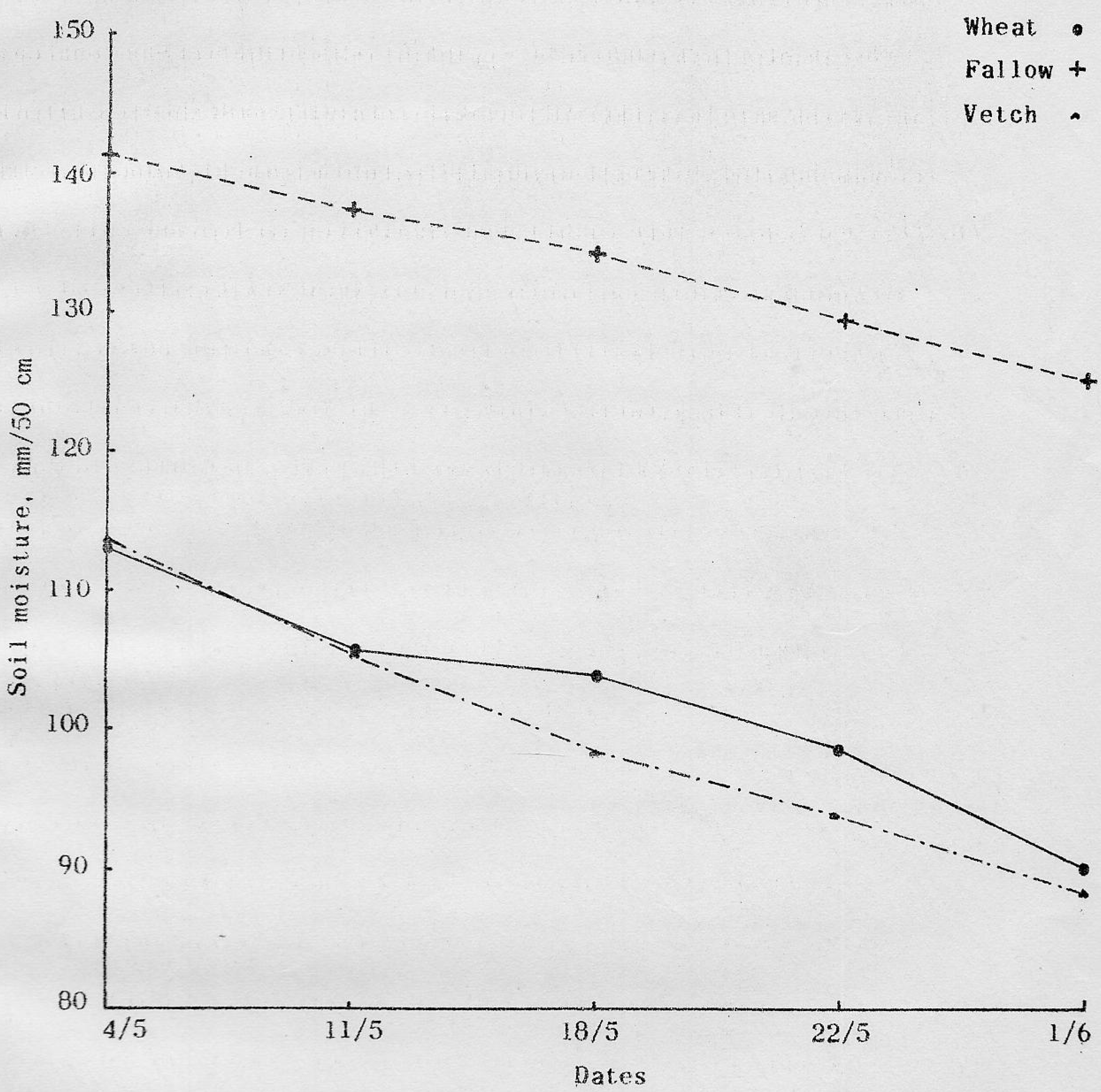

Figure 9. Soil moisture content in top 50 cm depth under wheat, fallow and vetch. May 1967.

From October 30, 1967 onward, soil moisture rose in all plots reaching field capacity in the second 50 cm depth, in early November, and in the top 50 cm depth in early December. From then to the end of February, soil moisture contents remained at or above field capacity reaching peaks of 150 mm or 12.78% greater than the field capacity, in the first depth and 155 mm or 13.10% greater than field capacity in the second depth, on February 28, with little difference between the three cropping patterns.

From February 28 to May 8, soil moisture was depleted, the rate being greater in the first 50 cm depth for wheat and vetch. On the latter date, the fallow plots had moisture contents of 98 mm or 34.24% greater than wheat and vetch in the first depth. This differential extraction of soil moisture from February 28 to May 8, is due to active growth of the wheat and vetch and their high rate of transpiration during this period. The rise of moisture content in the first depth for wheat and vetch in late May is explained by the 53 mm of rain which occurred on May 21 and 26. The effect of this amount of rain was to raise the moisture content of plots under wheat and vetch to almost equal that of fallow.

Considering the moisture content difference between October 30 to June 6, in the top meter of the soil (Tables 12, 13, and 14), soil under wheat had a net gain of 5.5 mm or 1.11% of the total precipitation compared with 2.9 mm or 0.57% for vetch and a loss of 11.2 mm or 5.06% for fallow soils although at this date, June 6, the moisture content of the fallow plot in the top meter was slightly greater than wheat and vetch.

Table 12. Soil moisture, precipitation, runoff, potential evapotranspiration, actual evapotranspiration and deep percolation on wheat plots, 1967-68.

Dates of soil moisture measurements	Soil moisture mm/meter	Precipitation mm	Runoff mm	Potential evapo-transpiration mm	Actual evapo-transpiration mm	Deep percolation mm
October 30	214.3					
December 5	276.7	91.8	1.53	34.40	17.20	10.67
December 19	284.0	42.9	0.42	9.64	9.64	25.54
January 9	294.7	82.0	2.49	13.92	13.92	54.89
January 23	290.6	110.0	3.90	9.68	9.68	100.52
February 28	306.8	93.5	4.39	35.65	35.65	37.26
April 3	239.0	27.2	0.80	60.01	60.01	34.19
April 17	212.0	0.0	0.0	36.39	27.0	0.0
May 8	194.0	2.0	0.0	61.77	19.50	0.0
January 6	219.8	53.0	1.05	105.14	26.65	0.0
Total		502.4	14.58	366.60	219.25	263.07

Table 13. Soil moisture, precipitation, runoff, potential evapotranspiration, actual evapotranspiration and deep percolation on vetch plots, 1967-68.

Dates of soil moisture measurements	Soil moisture mm/meter	Precipitation mm	Runoff mm	Potential evapo-transpiration mm	Actual evapo-transpiration mm	Deep percolation mm
October 30	209.0					
December 5	264.5	91.8	1.58	34.40	17.2	17.52
December 19	289.5	42.9	0.47	9.64	9.64	7.79
January 9	293.0	82.0	2.58	13.92	13.92	62.00
January 23	298.3	110.0	3.97	9.68	9.68	91.05
February 28	303.8	93.5	4.41	35.65	35.65	47.94
April 3	247.2	27.2	0.96	60.01	60.01	22.83
April 17	211.0	0.0	0.0	36.39	36.20	0.0
May 8	196.0	2.0	0.0	61.77	17.00	0.0
June 6	211.9	53.0	1.33	105.14	35.77	0.0
Total		502.4	15.30	366.60	235.07	249.13

Table 14. Soil moisture, precipitation, runoff, potential evaporation, actual evaporation, and deep percolation on fallow plots, 1967-68.

Dates of soil moisture measurements	Soil moisture mm/meter	Precipitation mm	Runoff mm	Potential evaporation mm	Actual evaporation mm	Deep percolation mm
October 30	232.5					
		91.8	1.77	36.7	18.35	33.58
December 5	270.6					
		42.9	0.32	10.28	10.28	26.10
December 19	276.8					
		82.0	2.27	14.84	14.84	59.99
January 9	281.7					
		110.0	3.30	10.32	10.32	81.88
January 23	296.2					
		93.5	4.50	38.02	38.02	46.38
February 28	300.8					
		27.2	0.86	64.02	64.02	2.92
April 3	259.5					
		0.0	0.0	38.82	15.50	0.0
April 17	244.0					
		2.0	0.0	65.88	14.00	0.0
May 8	232.0					
		53.0	4.00	112.15	59.70	0.0
June 6	221.3					
Total	11.2	502.4	17.02	391.03	245.03	250.85

The net loss of soil moisture under fallow from October 30 to June 6 is due to the high moisture content of the soil at the initiation of the experiment, October 30, due to the fact that the soil was under fallow during year 1966-67. Hence it is concluded that fallowing for two consequtive years under these conditions, was not more effective in conserving moisture than one year of fallow. However, considering soil moisture depletion from the top and bottom 50 cm depth of the soil in May 67 (Figures 8 and 9), fallowing was effective in conserving appreciable soil moisture during the year 1966-67. In the 1966-67 season the soil under the three cropping systems was at or near field capacity in early March, but by June the first, the top 50 cm layer of the fallow had 125 mm moisture compared with 90 mm and 88 mm for wheat and vetch, respectively, i.e. 47% above the permanent wilting point (85 mm) for fallow compared with 4% and 6% for vetch and wheat.

In the second depth, by June first, the moisture content of fallow plots was 16% greater than wheat plots and 23.5% greater than vetch plots, or it was 11.28% above field capacity on fallow plots, whereas the wheat and vetch plots were 4.5% and 11.28% below the field capacity.

Wheat and vetch crops, therefore, extracted moisture efficiently from the top 50 cm layer of the soil, but poorly from the bottom 50 cm layer of the soil.

These results are in general agreement with the findings of other workers. Mathews and Army (1940) summarized and analyzed moisture storage data during the fallow period of an annually cropped and alternately cropped, fallowed wheat land for over 450 crop-fallow periods. They showed that on the average 2.02 inches of water or 16.1% of the precipitation was stored during the fallow portion of an annually cropping system. Rafii (1964) working on the efficiency of fallowing in conserving moisture in the Beqa'a reported that there was a storage of 25.9 mm or 5.11% of the total 507.0 mm of precipitation from seeding to harvest of continuously cropped land as compared to 114.8 mm or 22.66% of the total precipitation stored on fallow plots during the same period.

Karaker et al. (1939) reported that wheat plants obtain water chiefly from top two to three feet of soil and do not root efficiently below a depth of 3 feet and the extent to which wheat could remove water was affected by increasingly sparse root development, with depth, that differed with different soils.

Consumptive Use

Values of consumptive use for wheat, vetch and evaporation from fallow plots for year 1967-68 are given in Tables 12, 13, and 14. Total consumptive use for wheat and vetch and evaporation from fallow was 21.9 cm, 23.5 cm, and 24.5 cm, or 43.64, 46.78, and 48.77% of the total precipitation, respectively.

Average daily consumptive use during each period between soil moisture reading is presented in Table 15. The vetch crop used moisture mostly during the period of February 28 to April 17. The peak being in early April with a rate of 2.58 mm per day. This is due to increasing temperature and initiation of the active growth of the crop. The water use for wheat crop was also high during this period, at 1.93 mm

Table 15. Daily and total water[x] use in mm by the three cropping patterns for each period between soil moisture measurements, 1967-68.

Measurement Interval	Wheat		Fallow		Vetch	
	Daily	Period	Daily	Period	Daily	Period
October 30 - December 4	0.47	17.20	0.51	18.35	0.47	17.20
December 5 - December 18	0.69	9.64	0.73	10.28	0.69	9.64
December 19 - January 8	0.70	13.92	0.74	14.84	0.70	13.92
January 9 - January 22	0.69	9.68	0.74	10.32	0.69	9.68
January 23 - February 27	0.99	35.65	1.06	38.02	0.99	35.65
February 28 - April 2	1.71	60.01	1.88	64.02	1.71	60.01
April 3 - April 16	1.93	27.00	1.10	15.50	2.58	36.20
April 17 - May 7	0.93	19.50	0.66	14.00	0.81	17.00
May 8 - June 6	0.92	26.65	2.06	59.70	1.23	35.77
Total		219.25		245.03		235.07

x. Based on the application of Penman's formula for the period of October 30 to April 3 and direct soil moisture measurement from April 3 to June 6.

per day.

The vetch crop used more moisture during the period of April 3 to April 17 than wheat, because of the fact that it matured earlier than wheat and flowering and seed setting stages are the periods when the crop needs for moisture are high.

The high water use from fallow plots during the period of May 8 to June 6 was due to abundant moisture in the soil, and with 53 mm rain in late May, considerable evaporation took place from the bare soil.

Deep Percolation

The full data on precipitation, runoff, soil moisture, consumptive use and deep percolation are given in Tables 12, 13, and 14.

The value of deep percolation for the whole year from vetch plots was 249.13 mm (Table 13) or 49.58% of the total rainfall, and those from fallow and wheat were 250.85 mm and 263.07 or 49.93% and 52.36% of the total rain (Tables 12 and 14). The deep percolation occurred mainly during the period of early December to late February.

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A two year experiment was conducted at the Agricultural Research and Education Center of the American University of Beirut to study runoff and its relationships with different parameters of rainfall viz; rain depth, kinetic energy, and Erosion Index, percent slope, length of slope, and plant cover.

To carry out the experiment nine runoff plots were laid out, using three different percentages of slope (2.5, 3.5, and 4.5); two lengths of slope and a rotation of wheat, fallow and vetch.

Concurrently the consumptive use of the crops (wheat and vetch), evaporation from fallow land and deep percolation were determined during the year 1967-68 by the use of the neutron scattering probe for soil moisture measurement and the application of Penman's formula for estimation of consumptive use during the rainy months.

The total amount of runoff during year 1966-67 ranged from 8.67 mm to 23.58 mm or 1.47% to 3.99% of the total precipitation. The corresponding values for the second year were 8.70 mm to 21.21 mm or 1.58% to 3.83% of the total precipitation. In both years the minimum runoff values were from the vetch plot with 60 meter length, while the maximum values of runoff in both years were from fallow plot with a slope of 2.5% and a length of 30 meter.

The parameter of rainfall which was most closely related to runoff was Erosion Index (product of kinetic energy times maximum 30 minute intensity), while rain depth was the least correlated. The percent slope did not affect the runoff significantly under the rainfall intensities experienced and over the slope range of the plots. Amount of runoff per unit area over the long plots was about 50% of that on short plots. The different crop covers did not result in substantial differences in runoff.

The total consumptive use for wheat and vetch during the year 1967-68 was 21.9 cm and 23.5 cm, respectively, while the total evaporation from the fallow plots was 24.5 cm over the same period. The peak of the rate of water use for wheat and vetch was in the first two weeks of April. Fallowing practice in the first year resulted in conserving moisture, but fallowing for two consequtive years did not improve the storage of moisture.

The wheat and vetch crops extracted moisture mainly from the top 50 cm layer of the soil and effective extraction from below 50 cm was not appreciable.

Deep percolation occurred mainly from December to March, and ranged from 24.9 cm to 26.8 cm or 49.58% to 52.2% of the total precipitation from vetch and wheat plots, respectively.

Since the total runoff is a small percentage of total precipitation under the experimental conditions, no special conservation practices are necessary. However, it is necessary that the experiment be continued over a much higher range of slope, i.e., from 2.5% up to 16% in order to be able to study the interaction effect of rainfall and percent slope.

There should be some refinements in the method of runoff measurement, i.e. automatic recording should be installed so that runoff corresponding to every single storm be recorded and hence closer interpretation obtained for the runoff capacity of individual storms.

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APPENDICES

Appendix 1

Kinetic energy of natural rainfall (foot-tons/acre inch) after Wischmeier (1958).

Intensity in/hr	.001	.01	.02	.03	.04	.05	.06	.07	.08	.09
0	-	254	354	412	453	485	512	534	553	570
.1	585	599	611	623	633	643	653	661	669	677
.2	685	692	698	705	711	717	722	728	733	738
.3	743	748	752	757	761	765	769	773	777	781
.4	784	788	791	795	798	801	804	807	810	814
.5	816	819	822	825	827	830	833	835	838	840
.6	843	845	847	850	852	854	856	858	861	863
.7	865	867	869	871	873	875	877	878	880	882
.8	884	886	887	889	891	893	894	896	898	899
.9	901	902	904	906	907	909	910	912	913	915
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	916	930	942	954	964	974	984	992	1000	1008
2	1016	1023	1029	1036	1042	1048	1053	1059	1064	1069
3	1074	1079	1083	1088	1092	1096	1100	1104	1108	1112
4	1115	1119	1122	1126	1129	1132	1135	1138	1141	1144
5	1147	1150	1153	1156	1158	1161	1164	1166	1169	1171
6	1174	1176	1178	1181	1183	1185	1187	1189	1192	1194
7	1196	1198	1200	1202	1204	1206	1208	1209	1211	1213
8	1215	1217	1218	1220	1222	1224	1225	1227	1229	1230
9	1232	1233	1235	1237	1238	1240	1241	1243	1244	1246

Appendix 2

Modified Penman evaporation formula after Lloyd *et al.* (1966)

R_1 = $(1-r)R_c$

R_c = $R_A\,(0.23 + 0.48\ n/N)$

R_B = $\sigma T^4\,(0.56 - 0.09\sqrt{e_d})\,(0.10 + 0.90\ n/N)$

H_T = $R_1 - R_B$

E_a = $0.35\,(1 + u/100)\,(e_a - e_d)$

E_T = $((\Delta/\gamma)\,H_T + E_a)/(\Delta/\gamma + 1)$

u_z = Run of the wind in miles per day

e_a = Saturation vapor pressure at mean air temperature, mm Hg

e_d = Actual vapor pressure, mm Hg

r = Reflection coefficient for the surface

R_1 = Effective short-wave radiation reaching the ground

R_B = Back radiation

R_c = Attenuated short-wave radiation reaching the ground

R_A = Short-wave radiation reaching the outside of the earth's atmosphere

n = Actual sunshine hours

N = Possible sunshine hours

H_t = Net radiation

E_a = Aero-dynamic evaporation

σT^4 = Black-body radiation at mean air temperature

γ = Constant of the wet and dry bulb physchrometer equation

Δ = Slope of the saturation vapor pressure curve at mean air temperature.

E_T = Potential evaporation from wet bare soil and actively growing green crops completely covering the ground.