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INCREASE FARM INCOME BY CONSERVING SOIL AND WATER.

Dr. Gerald G. Williams

Jakarta, 1989

MENINGKATKAN PENDAPATAN PETANI DENGAN KONSERVASI AIR DAN TANAH

oleh

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P R E F A C E

I wish to express much appreciation to Project Director S F C D P - USAID, Dr.Saroso Sindhoesaroyo for his assistance in introducing me to the many helpful administrators and specialists in the provinces and their arranging my field tours.

Much appreciation is extended also to the many field staff who spent time taking me to visit projects and farmers. Because of this help, I had some extra knowledge of the wide variety of soil and water conservation practices and needs in Indonesia when I wrote these training notes.

I also wish to express deep appreciation to Hendry Baiquni and Soegijanto for their very exellent assistance in making this publication possible. I especially thank to Hendry B. for helping me teach the first class using these notes, for his translation in the graphs, charts and the text of our notes. Thanks goes to both of them for helping in "lay out" the pages and printing. Thanks to Soegijanto also for help with the art work. I hope that those using these notes will have suggestions for improvement and forward suggestions to them. Their address is below.

Our hope is that students exposed to this information will realize how important it is for the farmers to know that rainfall energy is more than 200 times greater than the same amount of water in normal run off. If farmers can mulch their soil or have much crop residue, trash, leaves, stems on the surface and get the soil covered, very litle erosion will occur and run off is minimized.

Jakarta, September 1989

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INTRODUCTION

Much soil conservation planning and many projects all over the world over the past thirty years have failed. Hundreds of millions of dollars have been wasted and erosion was worse after measures were taken compared with the period before conservation activities were started. Why has this happened?

Because farmers were not properly involved. They did not understand what was being done and consequently did not have confidence in the plans. They were very cooperative during the construction of terraces and waterways because they were paid for their work.

However, when the project was completed and the supervisors went back to their own countries, the terraces, waterways and ditches broke down. There was no maintenance. These were "top-down" programs. It is now recognised that any soil conservation program must involve the farmer at an early planning stage. We should also understand that the small farmer needs to see a benefit in the short term as well as the longer run if he is to adopt a new idea. Also the risk element must be low.

Consequently, the farmer's attention needs to be focused on increasing water conservation and increasing yields. If, for example, he mulches the soil, the rate of infiltration will increase. More water will enter the soil and the rate of evaporation will be reduced.

In this way we need to help the farmer concentrate on increasing food production by conserving water as part of intensification of crop production. All farmers are interested in improving the yields of the plants they grow. We must help them to plan to do this.

The following pages are lessons learned from field research undertaken by many people. It is hoped that they will furnish ideas for training and discussions that will stimulate ideas to help conserve and use some of our resources more efficiently.

The field research at Watkinsville, Georgia, U.S.A. began in the 1930's. Many soil covers were planted including legumes and different types of grasses. Since nitrogen fertilizer was very expensive and difficult to obtain at that time, legumes used in the grass covers to conserve water and reduce erosion also provided nitrogen and were ploughed in for the following row crop. This was the farmer's <u>short term reward</u>. He made better yields in the short run.

Millions of farmers all over the United States began to use these legume/grass rotations, terrace their fields and adopt contour planting for row crops. In Indonesia we need to look for

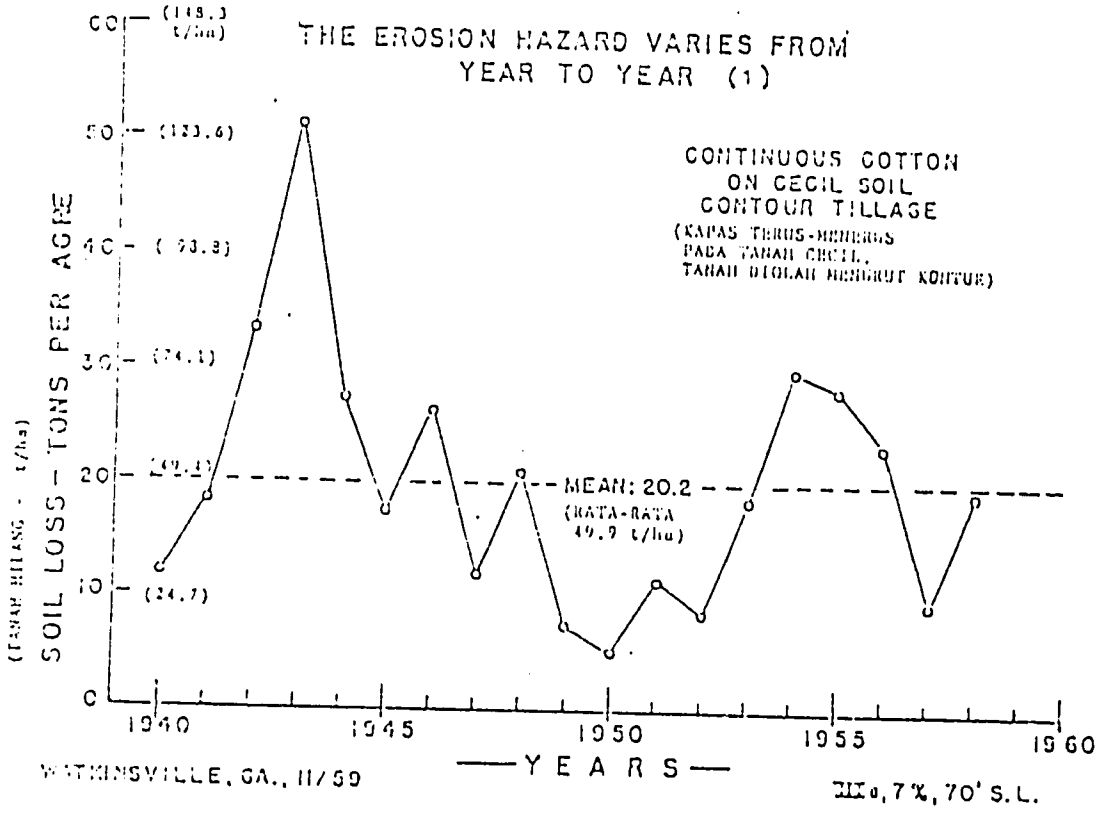
ways for the farmer to make increased yields at the same time he undertakes soil and water conservation.

Results from the Watkinsville Soil and Water Conservation Experimental Station (Southeastern United States).

Many factors causing soil erosion and water runoff have been studied over many years in the field research program at Watkinsville. Among these factors are rainfall, soil conditions, per cent slope of the soil surface, length of slope, land conservation practices, cropping systems including the effect of ground covers of grasses and legumes. Rotations of row crops following one or two years of grass or legumes was also studied. Since cotton was the primary cash crop during that period it was also included in most experiments.

The following graphs help summarise many of their more significant findings.

The Erosoin Hazard varies from year to year.

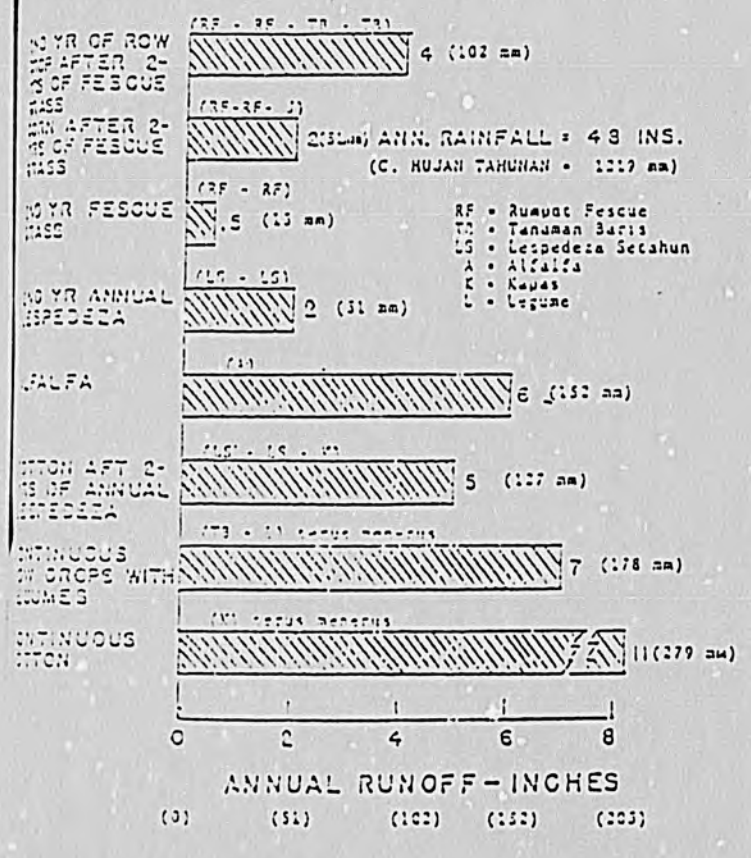


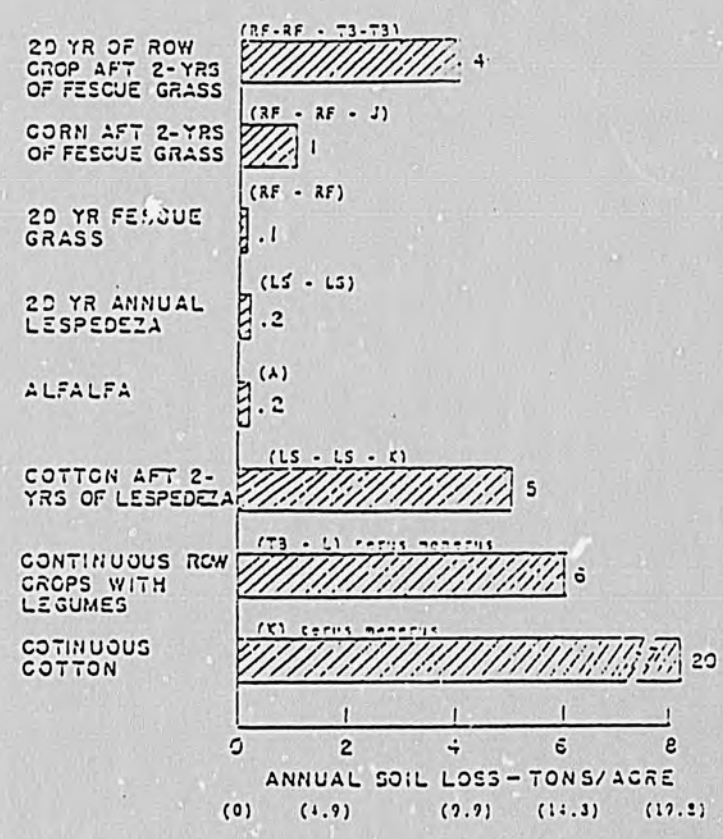
They found that erosion varied greatly during the period from 1940 to 1959. Though the above results were for continuous cotton planted on a 7% slope, the erosion was as high as 130T/Ha (1943) to as little as 11T/Ha (1950).

The two following figures show some of the effects of different crop rotations on water runoff and soil erosion. These experiements were on 7% slope and terreaced with rows planted on contour.

Reduction of Runoff by different cropping systems on Class IIIe land.

Reduction of Soil Loss by different cropping systems on Class IIIe land.

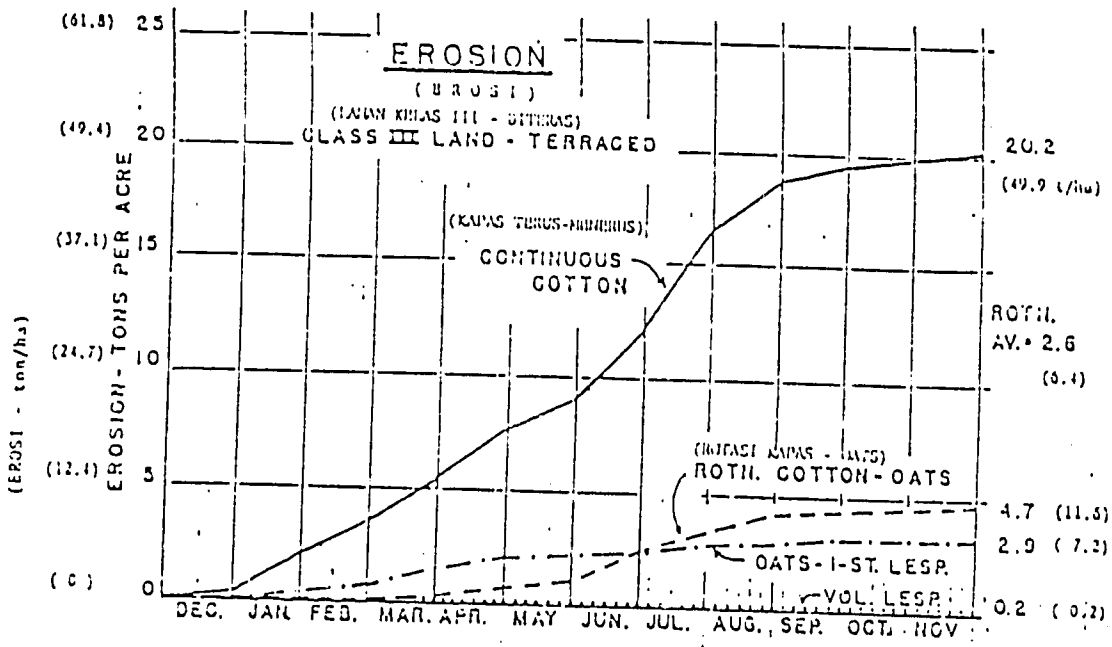




It was found that grass or legume sods reduced erosion to almost zero, and that row crops following two years of grass/legume covers were usually at acceptable levels of soil loss. for a period of one or two years. Notice also that water conservation was also influenced. Legumes were desirable to have in the rotation to furnish ntrogen since nitrigen fertilizers were not easy to obtain and also very expensive.

If cotton was planted continuously on a 7% slope, erosion and run off were excessive. Many diffeent cropping systems reduced erosion to acceptable levels.

3-Year Rotation -"Kobe Lespedeza Base"

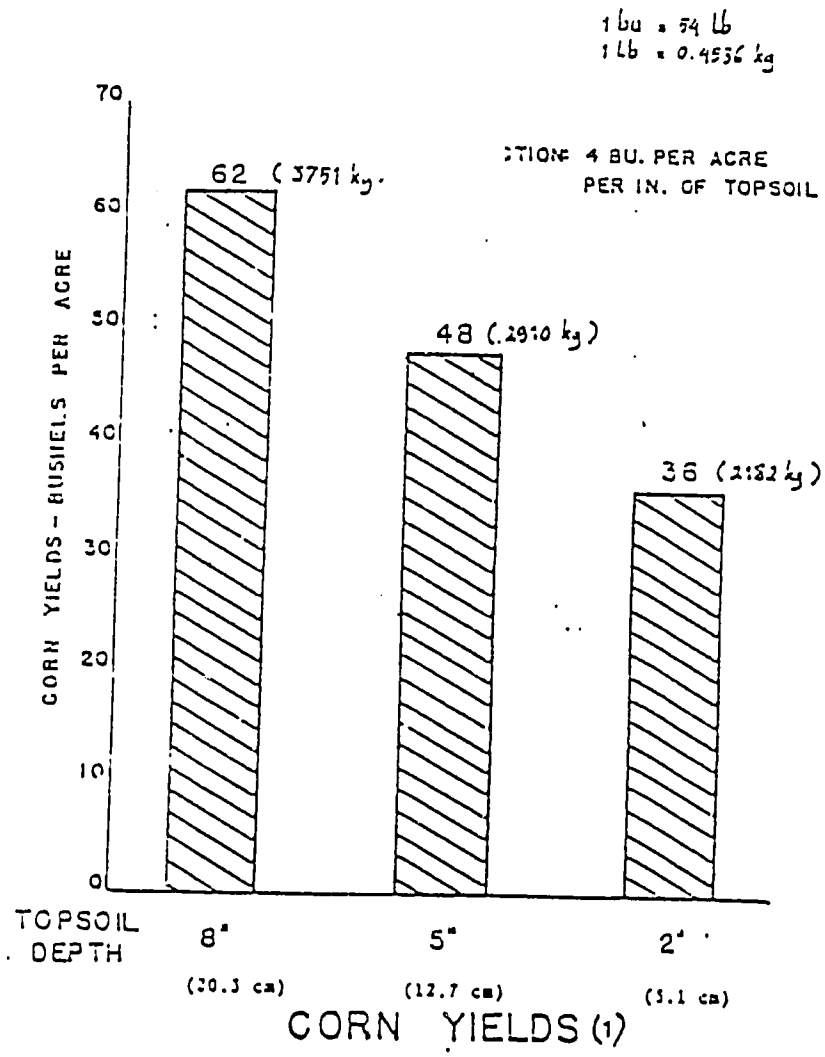


3-YEAR ROTATION -"KOBE LESPEDEZA BASE" (1)

12-YR. AV. 1940-52

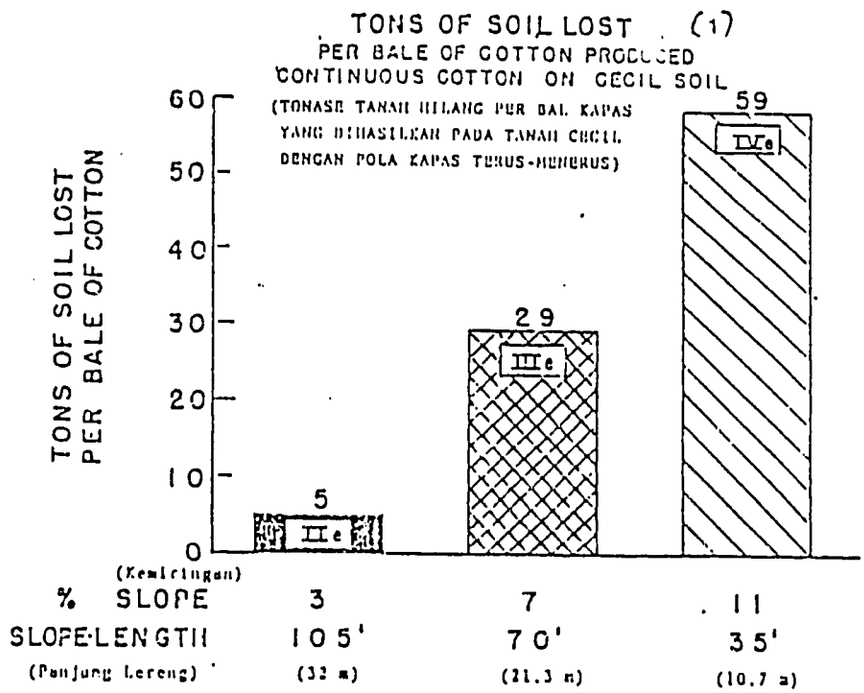
In a number of experiements the depth of top soil greatly affected crop yields. In the following experiment with corn, the 20 cm top soil produced 3,750 kg/Ha compared with 2,180 kg/Ha when 15 cm of top soil was removed.

Corn Yields.



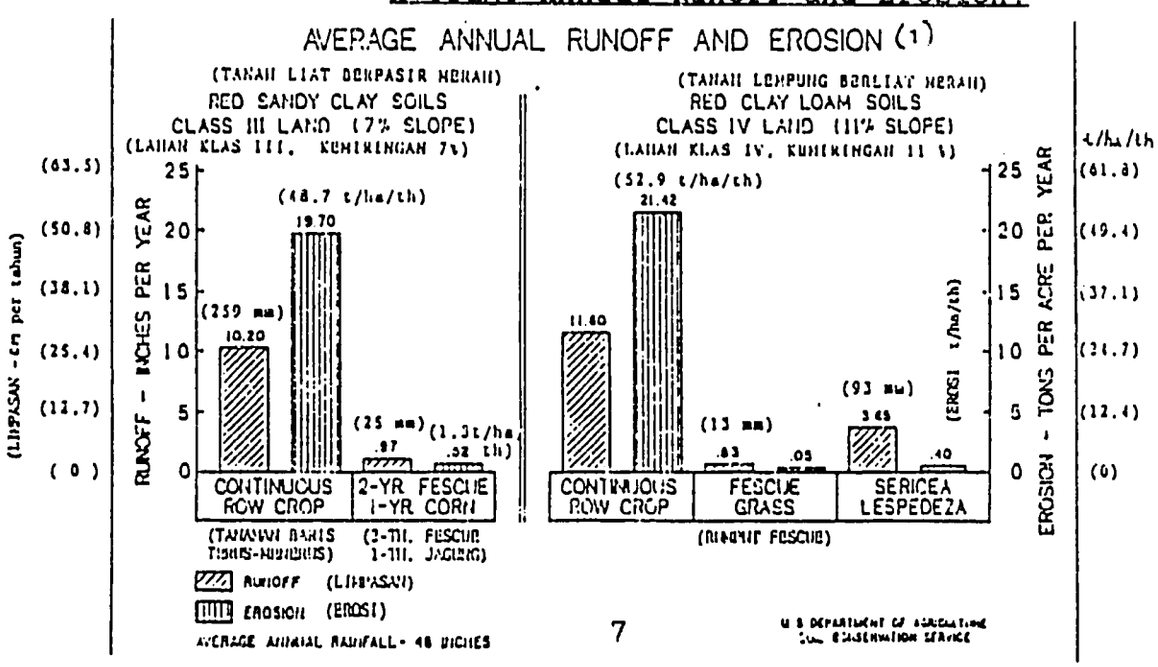
Soil loss increased greatly as slope increased. Crop yields were inversely proportional to slope as you might expect.

Tons of Soil lost.



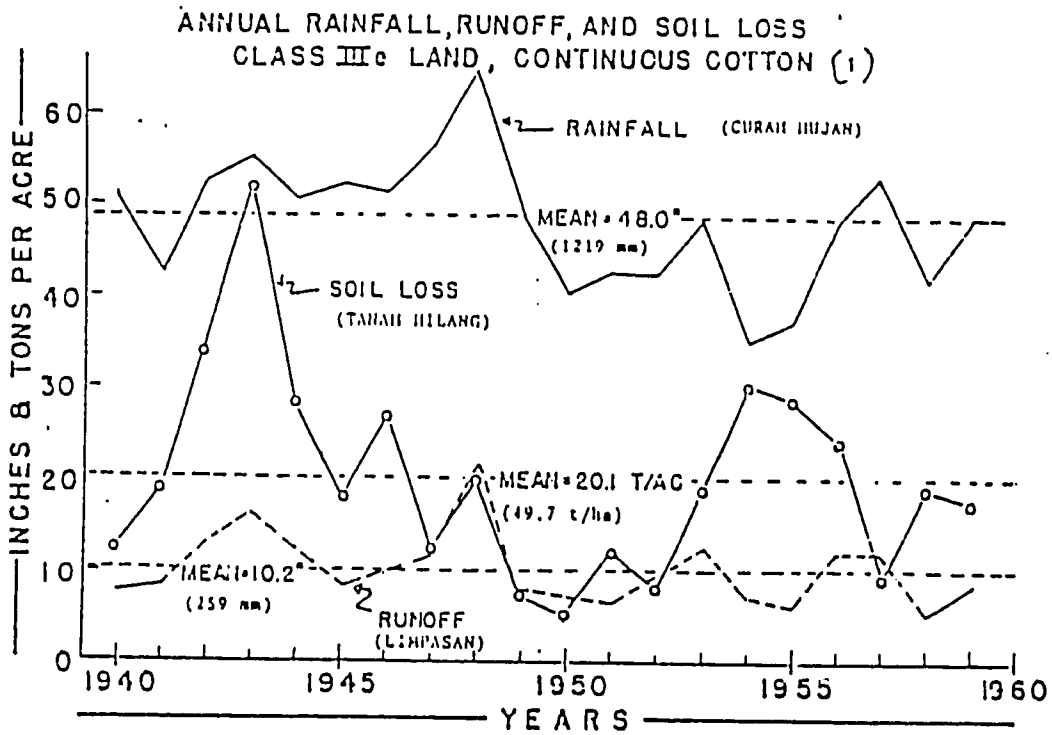
Two years of fescue grass followed by one or two years of corn proved to be a succesful rotation in reducing soil loss and increasing water conservation. When legumes were included and interplanted in the grass, the following row crop yields were higher.

Average Annual Runoff and Erosion.



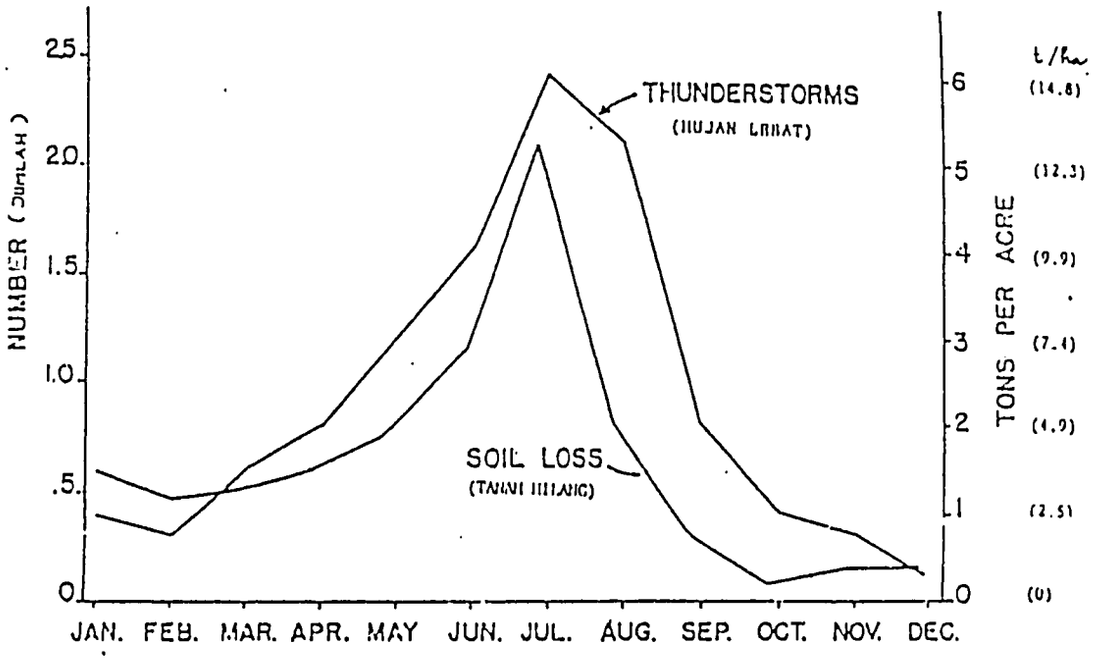
A careful study of the following record of annual rainfall, soil loss and rainfall runoff reveals some interesting points. Notice that the rainfall and soil loss varied greatly over the years 1940 - -1959. Note that although water runoff was similar the trend of annual rainfall, soil erosion did not.

Annual Rainfall, Runoff, and Soil Loss on Class IIIe Land: Continuous Cotton.



Rainfall records were studied in more detail. When the continuous recording raingauge data was examined and those storms which recorded 2.54 cm or more rainfall per half hour (named thunder storms) were further examined, a great discovery was made. The trend of thunder storms closely followed the soil loss trend.

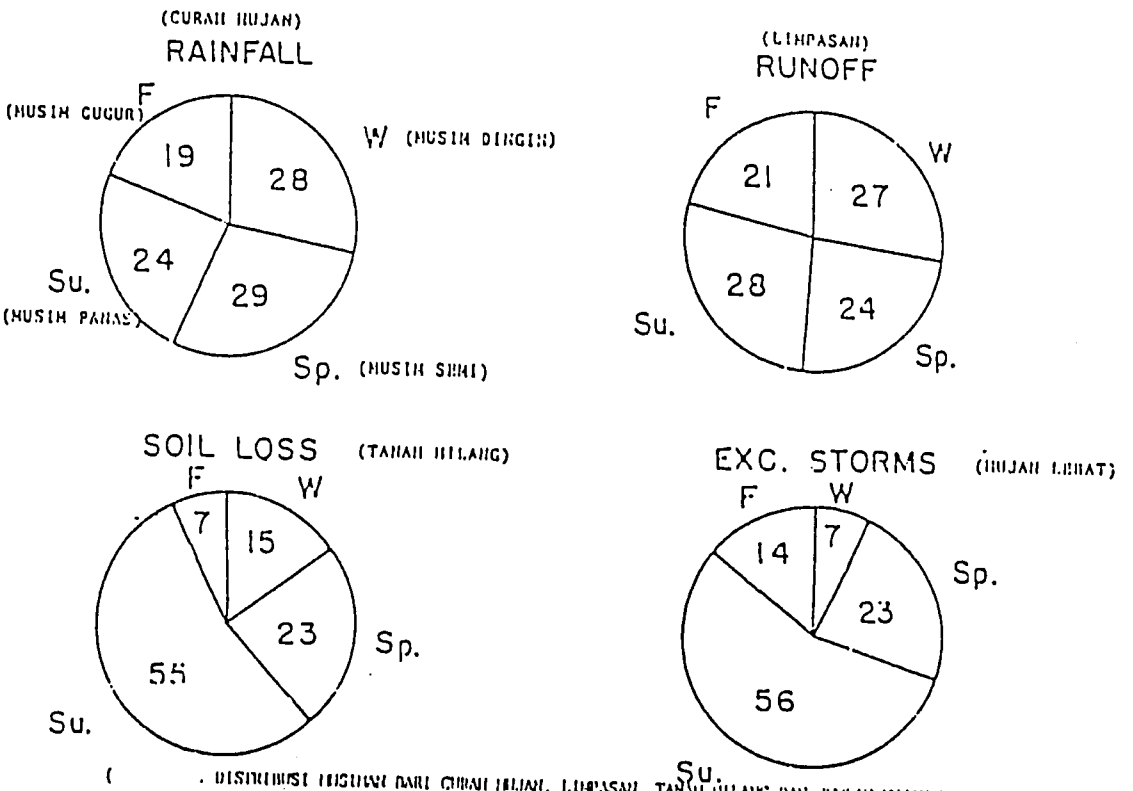
Thunder Storms and Soil Losses.



Average monthly distribution of soil loss and number of thunderstorms.

When the rainfall, runoff and soil loss data was examined in light of this new knowledge, it showed that rainfall and runoff were more or less divided equally over the four seasons, summer, fall, winter and spring.It was discovered that during the three summer months 55% of the soil loss occured along with 56% of the thunder storms.

RAINFALL, RUNOFF, SOIL LOSS & EXCESSIVE-RATE STORMS.

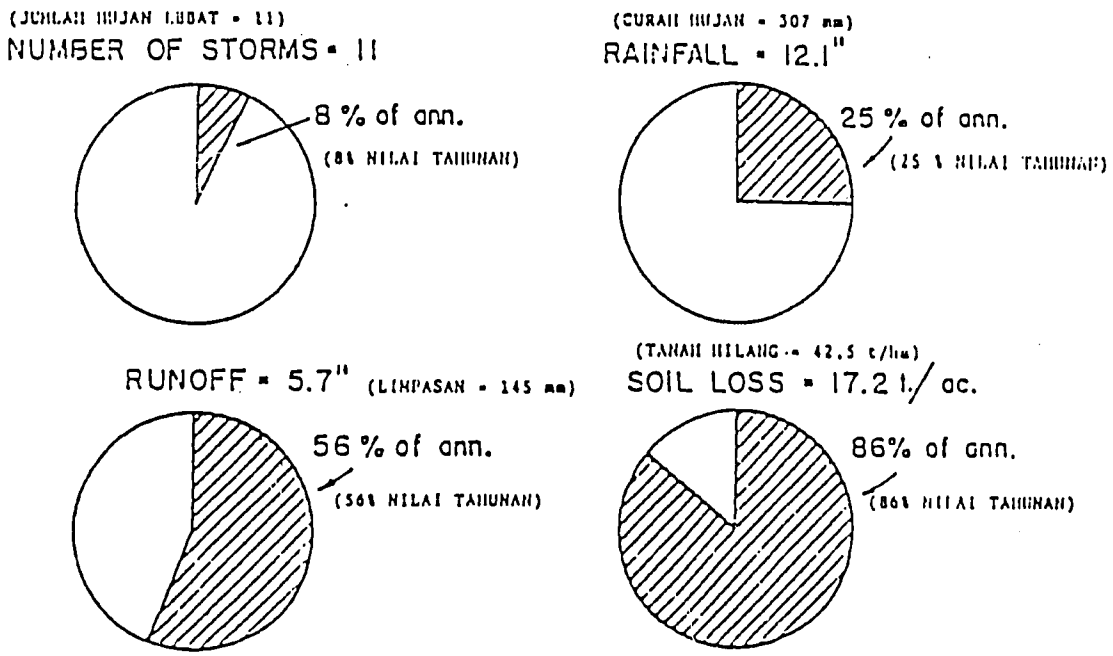


(. DISTRIBUSI MUSIMAN DARI CURAH HUJAN, LIMPASAN, TANAH HILANG DAN JUMLAH HUJAN LEBAT).

Seasonal distribution of rainfall, runoff, soil loss, and number of excessive-rate storms. (1)

When the thunder (excessive-rate) storm data was examined further, it showed that these eleven excessive-rate storms, though only 8% of the total annual storms, accounted for 25% of the annual rainfall, 56% of the runoff and 86% of the annual soil loss.

Number of Storms, Rainfall, Runoff & Soil Loss.



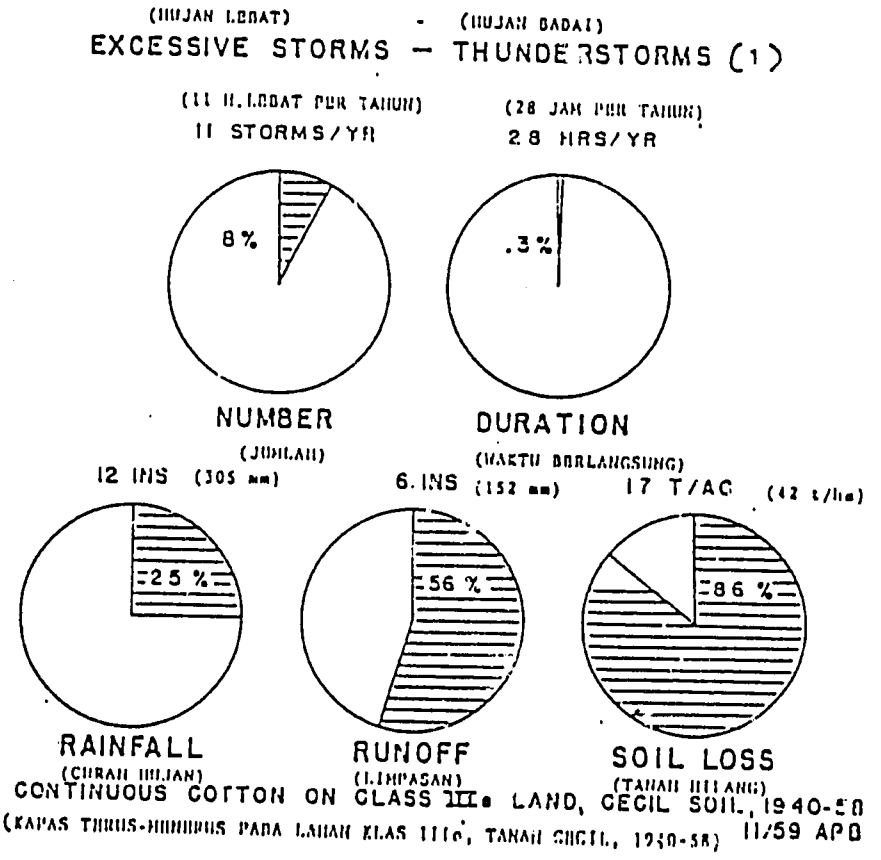
The average number of excessive-rate storms per year and amount and percentage of total rainfall, runoff, and soil loss attributed to these storms.

(. RATA-RATA JUMLAH HUJAN LEBAT PER TAHUN DAN JUMLAH SERTA PERSENTASE TOTAL CURAH HUJAN, LIMPASAN DAN TANAH HILANG AKIBAT HUJAN LEBAT TERSEBUT). (1)

When this rainfall data is reexamined on an annual time scale, 86% of the soil loss occured in only a 28 hour period for the year!

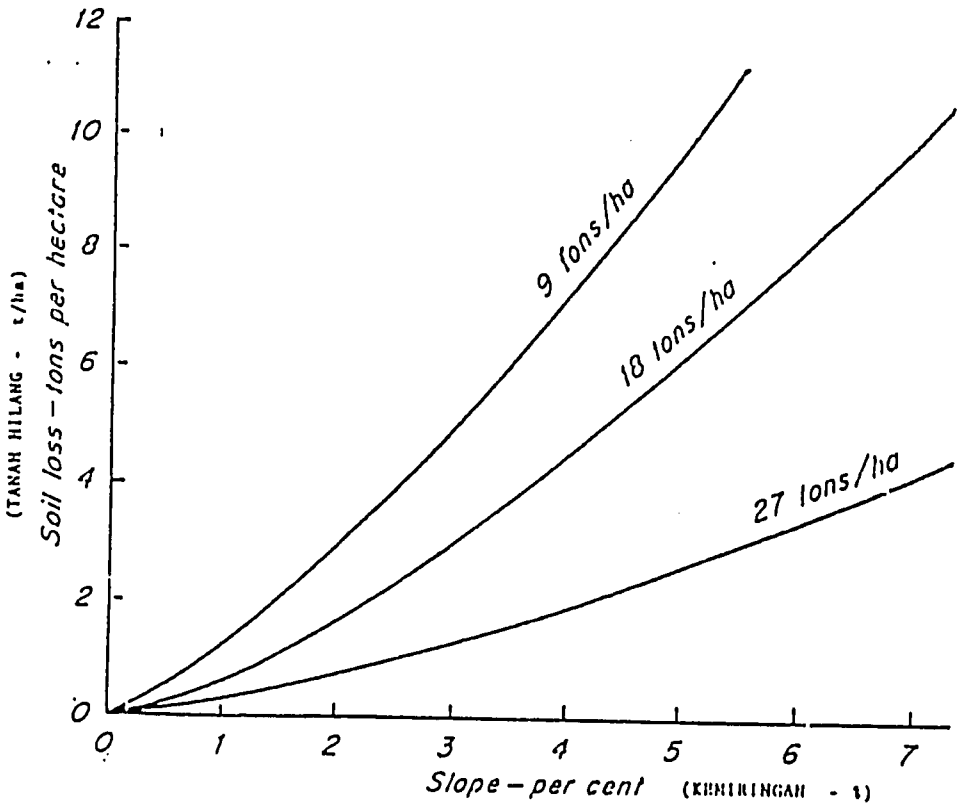
Excessive Storms - Thunderstorms.

Number, Duration, Rainfall, Runoff, Soil Loss.



Work at the Watkinsville Research Station and 27 other research stations across the United States, as well as work in Africa and other countries, showed that % slope very definitely affected soil erosion as well as run off and yields. Another factor which interacts with erosion and slope is the level of crop production. If good husbandry is used, proper plant spacing and correct fertilizer applications applied according to soil test recommendations, this affects soil loss very significantly, as shown in the following graph.

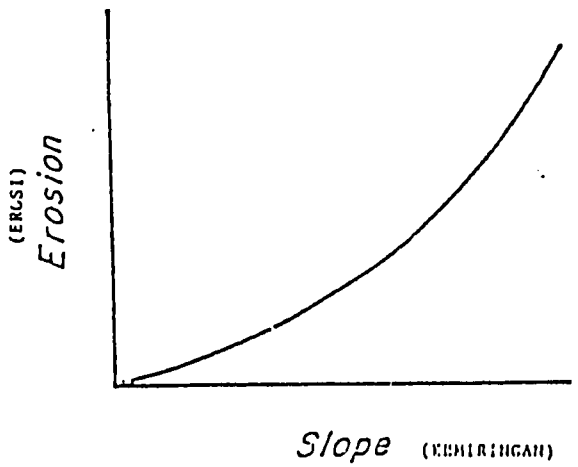
The effect of slope for different levels of erosion.



The effect of slope on erosion for different levels of production of maize
(PERHUBUNGAN KEMIRINGAN LERENG TERHADAP HASIL UNTUK BERBAGAI TINGKAT PRODUKSI JAGUNG) (4)

Hudson discusses the efects of slope and length in some detail. He suggests combining slope and length of slope when dealing with them quantitatively in dealing with the Universal Soil Loss Equation. The following graphs which were prepared from data from many sources indicate that the steeper the slope, the greater the erosion. There are a number of reasons which indicate that the greater the raindrop force splashing soil down hill, the more and faster the runoff. The amount of erosion is not just proportional to the steepness of the slope but rises rapidly as the slope increases as shown in the following graph.

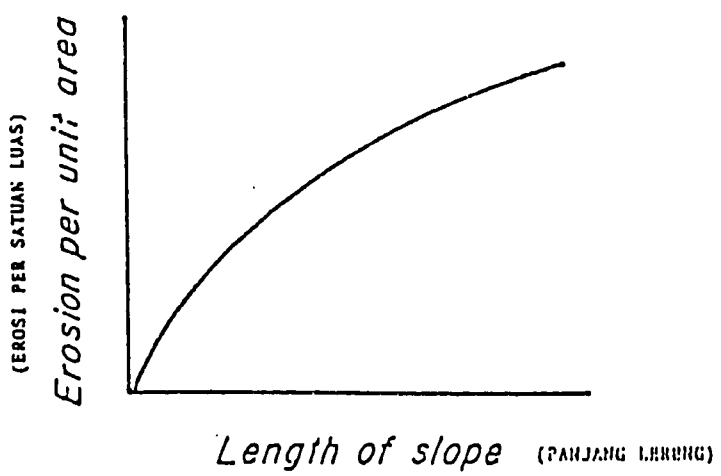
The relationship between erosion and slope.



The relationship between erosion and slope

To quote HUdson again, "on a long slope there is a bigger build up of the amount of surfce runoff and its velocity and depth. This will lead to scour (or gully) erosion which would not occur on a shorter length of slope".

The relationship between erosion and length of slope.

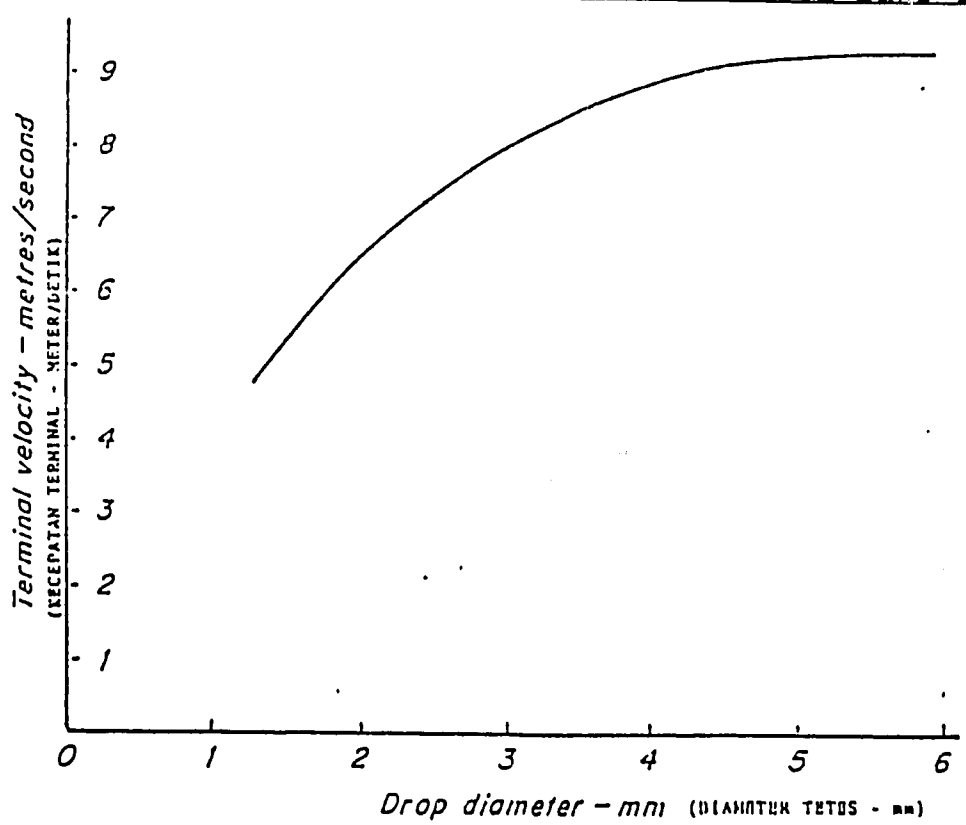


The relationship between erosion and length of slope

FUNDAMENTAL RAINFALL RESEARCH

Whilst applied field research was being done at 28 experimental stations across the United States and also in Africa, soil and water physics was being investigated in a more fundamental manner. The raindrop especially was under investigation. Tall towers were built with a water supply and rain drop forming equipment at the top. Different types of raindrop tracking and catching devices were used. Researchers wanted to know how large they could make rain drops and what their terminal velocities were when they hit the earth. They made artificial rain drops of known size and weight and would release them from a great height. Then by high speed photography the speed of fall was calculated. Later other researchers created an electric charge on rain drops and measured the rain drop speed as it passed through electromagnetic fields. The most credit in this research must go to a Dr Laws. He found that drops tended to break apart when their diameter exceeded 6 mm but at 5 to 6 mm, the terminal velocity was about 9 meters per second, going down to less than 5 metres per second with a diameter of 1 mm, as shown in the following graph.

The terminal velocity of raindrops (data from Laws 1941).

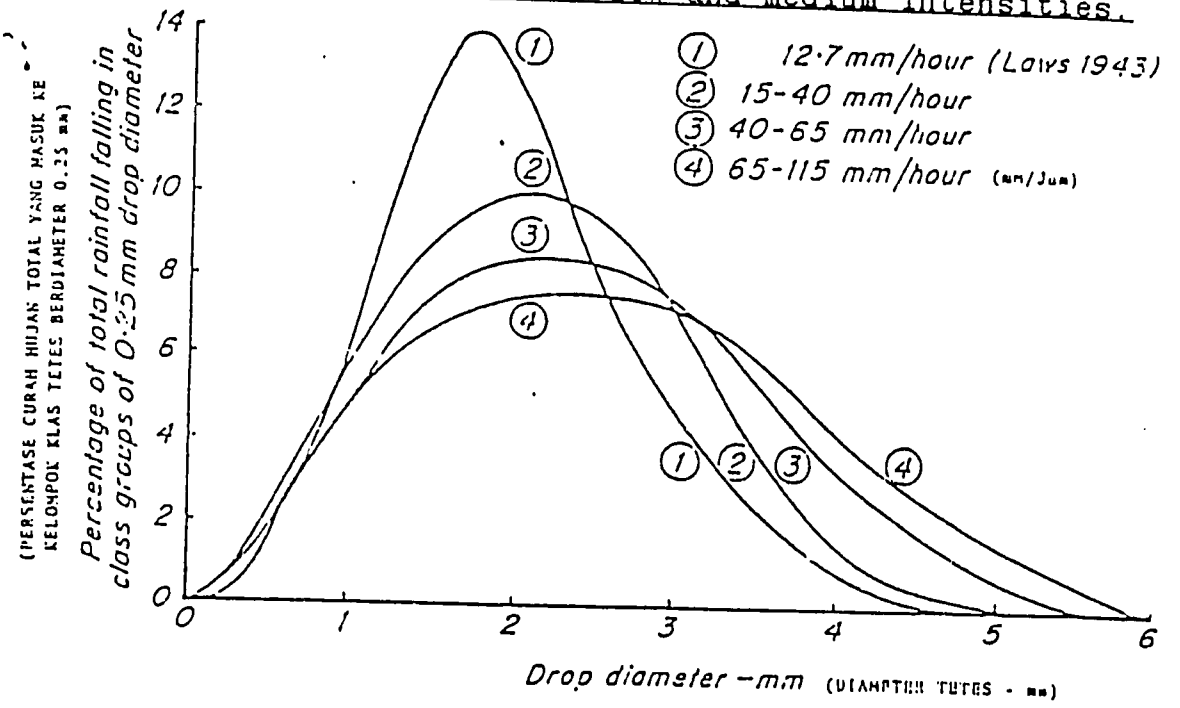


The terminal velocity of raindrops (data from LAWS 1941)

Much research was done to catch actual raindrops in different kinds of rainstorms.

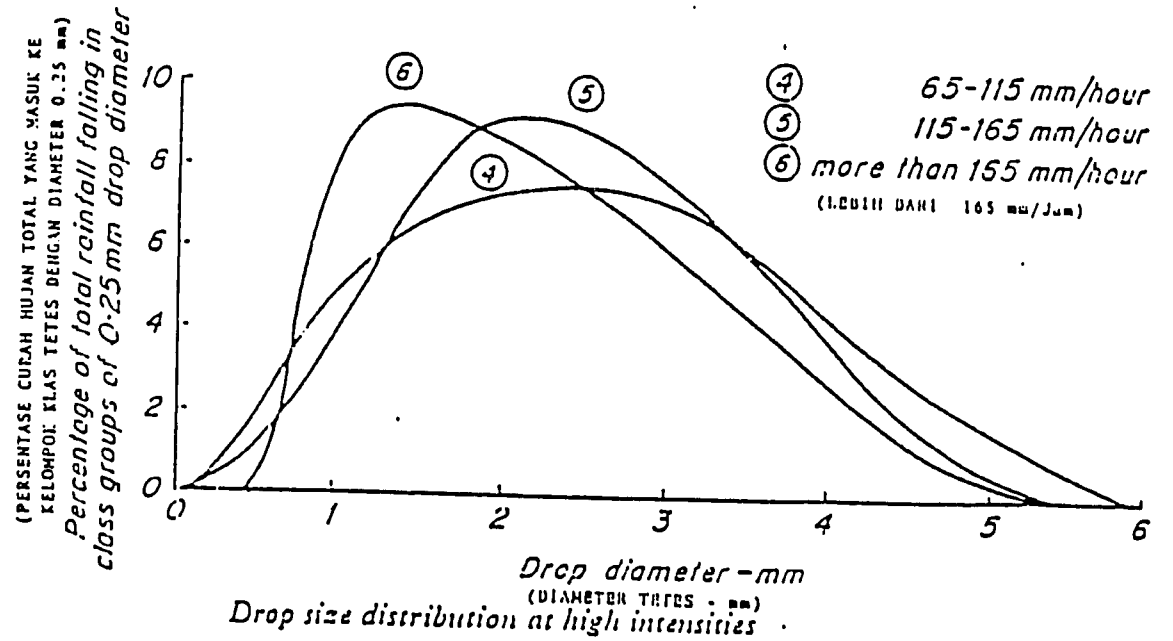
A lot of information was discovered about raindrop size at different intensities of rainfall. The two graphs below show rainfall in mm/hour ranging from 12.7 mm/hr to a high of 165 mm/hr. Note the shift in drop size from smaller to larger drops again from 12 mm/hr to 115 mm/hr but an apparent reduction in size when intensities exceed 115 mm/hr.

Drop size distribution at low and medium intensities.



Drop size distribution at low and medium intensities

Drop size distribution at high intensities.

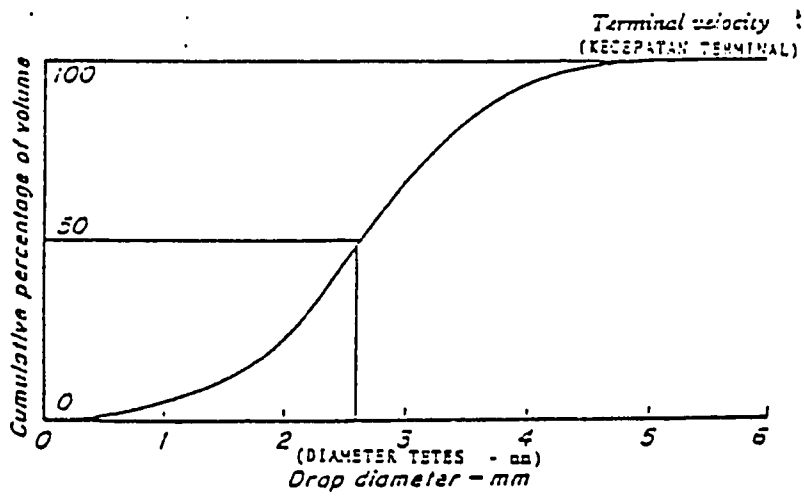


Drop size distribution at high intensities

Hudson indicates that the median diameter seems to be rather stable at 2 mm to 2.5 mm for intensities of 25 mm/hr to 150 mm/hr. Even at 2.5 mm diameter, a rain drop reaches a terminal velocity of more than 6 metres per second. Large drops reach velocities of 9 metres per second.

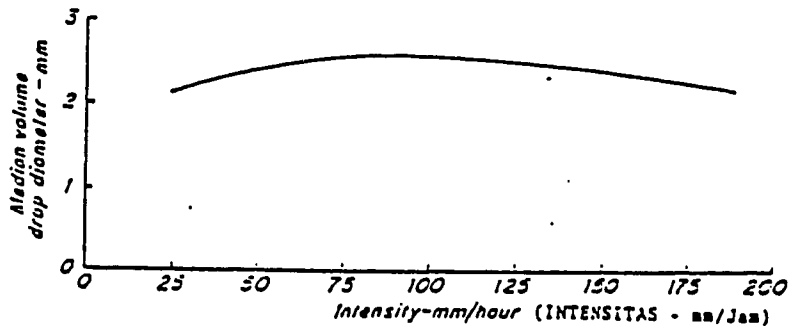
Hudson comments with regard to terminal velocity, "A body falling freely under the force of gravity will accelerate until the fractional resistance of the air is equal to the gravitational force and will continue to fall at that speed. This is known as a terminal velocity and depends upon the size and shape of the body. A feather has a very low termial velocity which is reached after a fall of a few centimetres but a bomb dropped from an aircraft duly reaches its very high terminal velocity after falling many thousands of metres .... the terminal velocity of a 5 mm rain drop is about 9 mm/second."

Finding the median volume drop diameter (D50).



Finding the median volume drop diameter (D50)

The relation between median volume drop diameter and intensity.



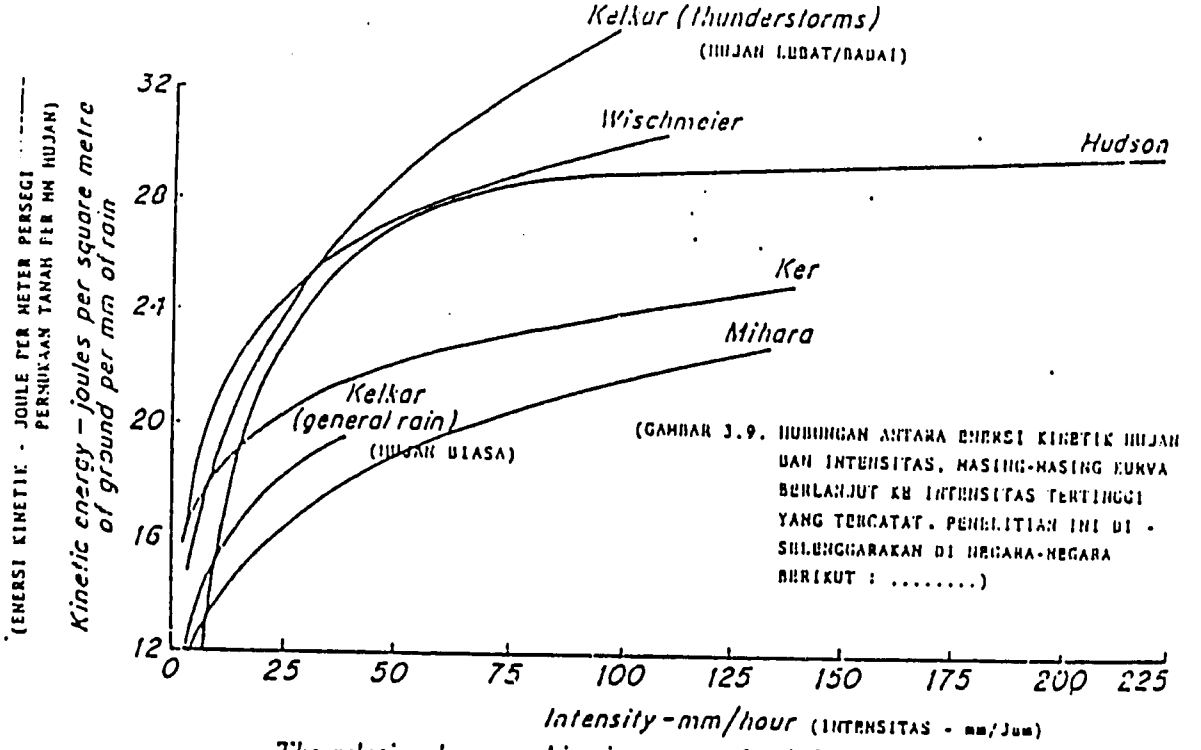
The relation between median volume drop diameter and intensity

Many rainfall researchers point out the high ability of rain to cause soil erosion. A.P. Barnett at the Watkinsville Research Station also researched the impact of energy in rainfall and showed that thunderstorms caused 86% of the annual erosion in only 28 hours. High speed photography shows the rain drops hitting the soil in the same manner as small bombs. They create small craters in the soil surface and splash the soil particles 4 or 5 centimetres up into the air.

Hudson goes on to point out that this splash erosion force is 256 times as great as the normal force of rainwater flowing over the soi surface at one metre per second.

The following graph shows the relationship between rainfall intensity and kinetic energy (Joules per square metre soil per mm rainfall). Each curve has been made by different a different researcher in a different country but with similar results. Hudson's research in Africa which measured the intensity up to 225 mm/hour reveals a constant energy level of 28 Joules/m per square meter soil per mm/rainfall when the intensity reached about 75 mm/hour to the highest level recorded, that is 225 mm/hour.

The relationship between kinetic energy of rainfall and intensity. Each curve extends to the higest intensity recorded. The studies were carried out in the following countries: Hudson-Rhodesia, Kelkar-India, Ker-Trinidad, Mihara-Japan, Wischmeier-United States.



The relation between kinetic energy of rainfall and intensity. Each curve extends to the highest intensity recorded. The studies were carried out in the following countries: HUDSON—*Rhodesia,* KELKAR—*India,* KER—*Trinidad,* MIHARA—*Japan,* WISCHMEIER—*United States* (4)

The energy in rainstorms causing splash erosion is the primary cause of erosion. Research shows that if this energy is intercepted very near the soil surface and the same amount of water then gently drips to the soil surface that no significant erosion occurs.

There are many ways to intercept and reduce the effect of rain energy which causes splash erosion. Hudson stretched mosquito netting a few centimetres above the soil surface. Researchers in other tropical locations around the world have repeated this work and many have found that good grass swards covering the soil or a mulch will do the same thing as mosquito netting..... that erosion can be reduced to zero or to almost zero.

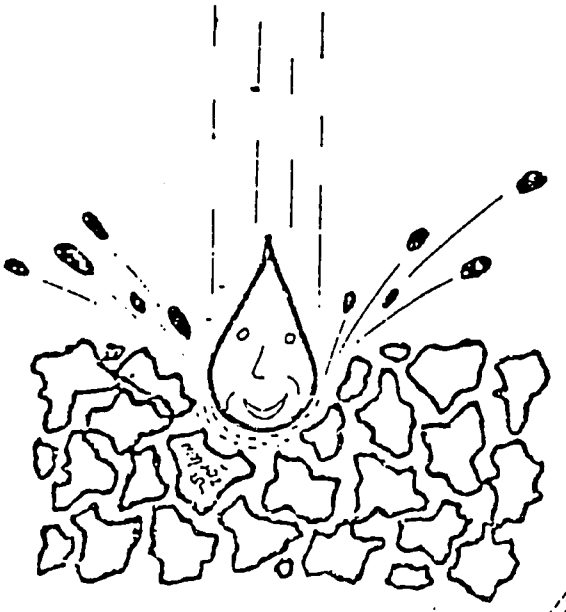
Kinetic energy of rain and run-off (ENERGI KINETIS HUJAN DAN LIMPASAN)

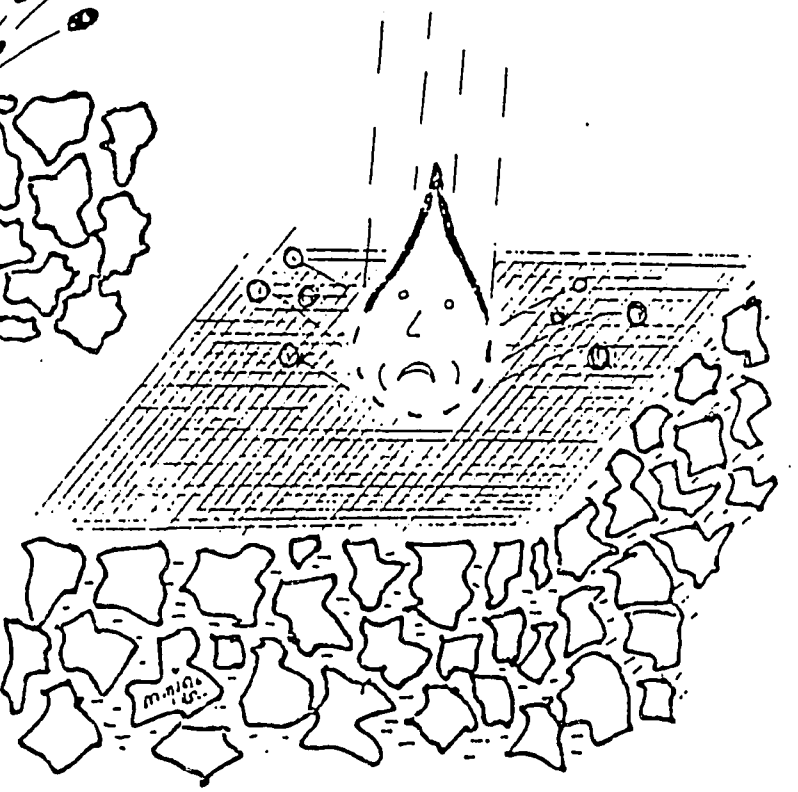
$$\text{Kinetic energy} = \tfrac{1}{2} \times \text{mass} \times (\text{velocity})^2$$

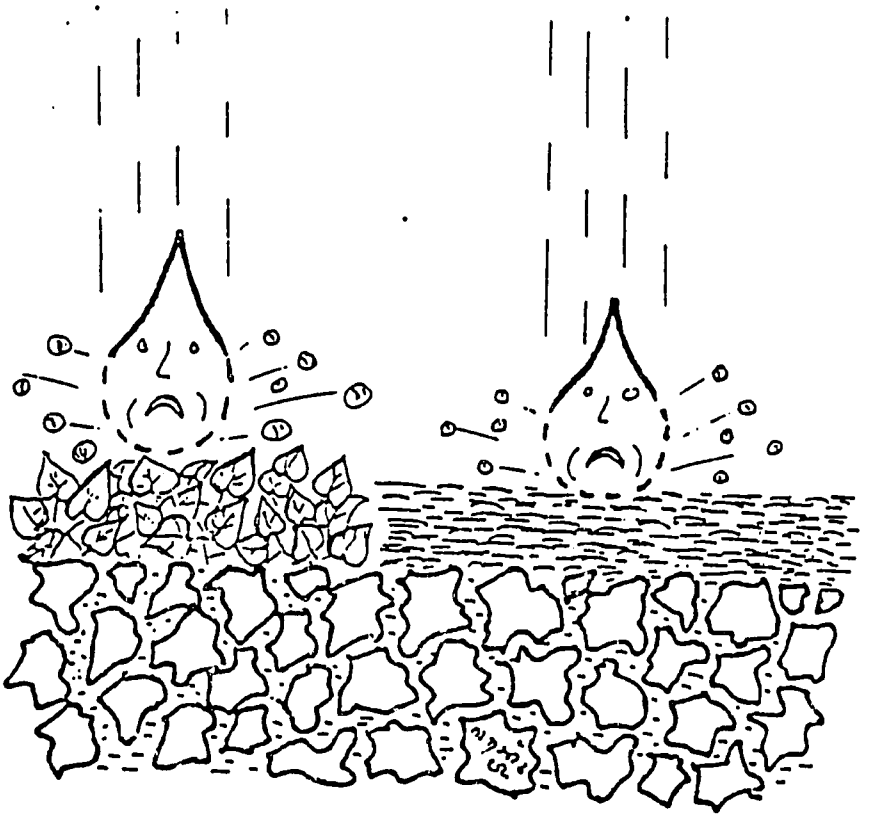
(ENERGI KINETIS = (1 x massa x (kecepatan)^2) (4)

	Rain	*Run-off*
Mass (MASSA)	Assume the mass of falling rain is R (DIASUMSIKAN MASSA DARI HUJAN YANG JATUH ADALAH R)	(DIASUMSIKAN 25% LIMPASAN) Assuming 25% run-off, mass of run-off is $\frac{R}{4}$ (MASSA LIMPASAN ADALAH R/4)
Velocity (KECEPATAN)	Assume terminal velocity of 8 m/sec (DIASUMSIKAN KECEPATAN TERMINAL 8 m/detik)	Assume speed of surface flow of 1 m/sec (DIASUMSIKAN KECEPATAN DARI ALIRAN PERMUKAAN 1 m/det)
Kinetic energy (ENERGI KINETIS)	$\frac{1}{2} \times R \times (8)^2 = 32R$	$\frac{1}{2} \times \frac{R}{4} \times (1)^2 = \frac{R}{8}$

The rain thus has 256 times more kinetic energy than the surface run-off.







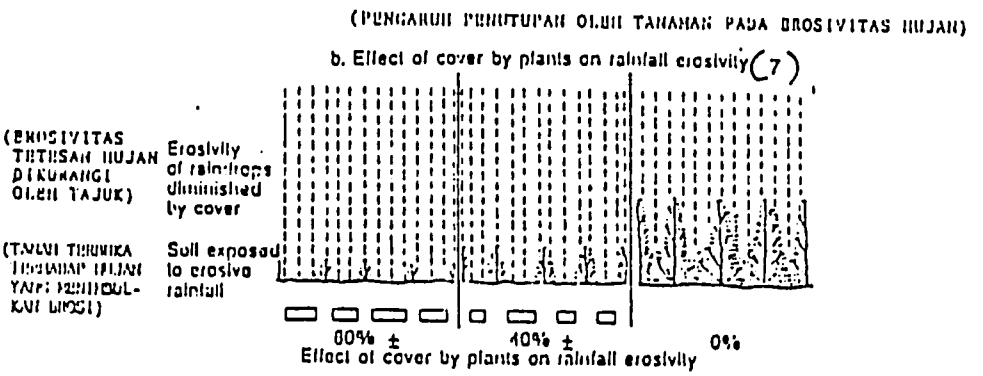
Rain drop Energy.

What would a farmer do if he fully understood that high energy, high intensity rainfall caused splash erosion and could be stopped by some kind of simple soil cover? This cover could be a healthy growing crop whose leaves overlapped before the heavy rains begain. Or it could be provided by plant residue or mulch, or by any kind of leaves or straw spread evenly over soil exposed to peak storms. There is a good argument for mulch. Not only does it keep erosion under control but it also increases water infiltration, and lowers soil temperature and revaporation. It also increases organic matter.

We know that a good grass sod eliminates erosion. We also know that if a two or three year old grass sod is turned under one can grow a row crop on it the following year without any significant erosion taking place. Some more advanced farmers might be interested in "minimum tillage" or "no-till" practices.

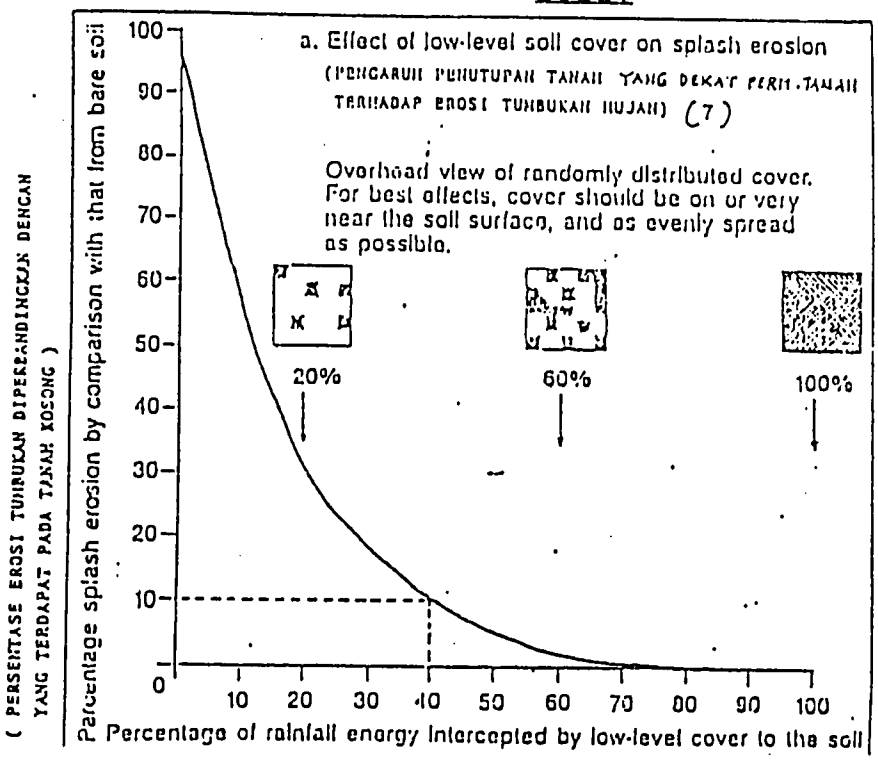
The following graph shows how soil cover increases as the planted crop matures.

Effect of cover by plants on rainfall erosivity.



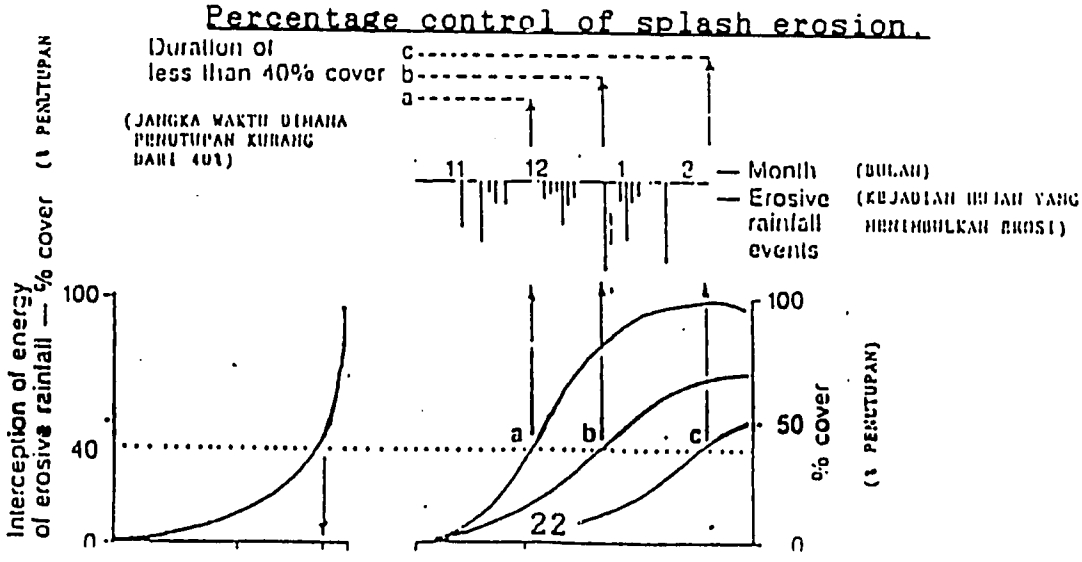
If 100% ground cover is not possible, lower percentages of ground cover are stillimportant. Research has shown that 40 or 50% ground cover may significantly lower erosion. One research report indicated that 40% ground cover, well distributed, lowered erosion to 10%. See the following graph.

Percentage of rainfall energy intercepted by low-level cover to th soil.



One possible way to avoid serious erosion might be to organize planting dates at a suitable time. If the high intensity rainfall periods are known, the farmer may be able to have his crops already growing well, with significant soil cover from growi plants, when the peak storms come. See the following graph.

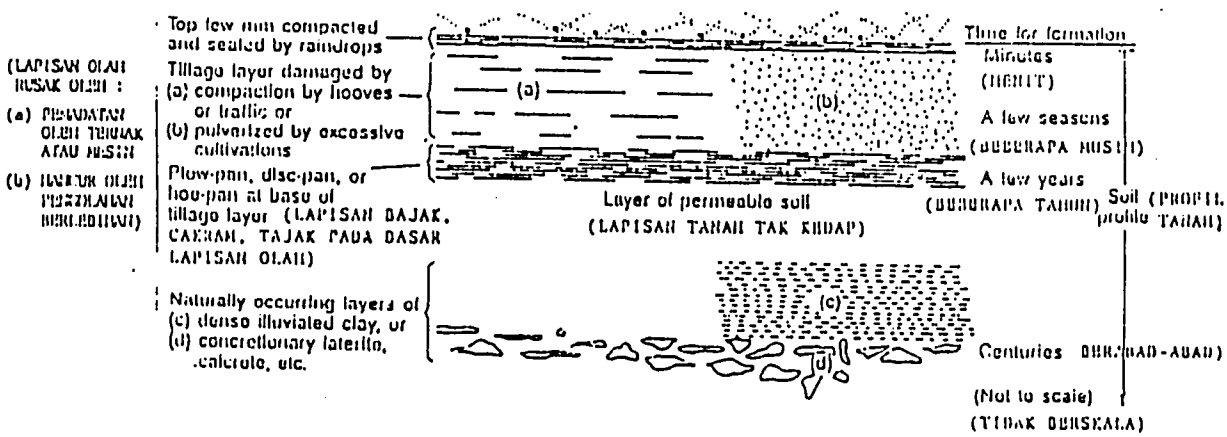
Percentage control of splash erosion.



Some people think that water conservation is more important to farmers than soil conservation. The basis of this opinion is that in the process of conserving water, farmers yields will increase and soil conservation will also take place.

Rain drops splashing on the soil surface tend to form a seal over the surface, compact the top soil and prevent rapid water entry into the soil. If the soil is mulched, or has a grass cover, water is free to enter rapidly. Some soils have other compacted layers such as a plow-pan where years of plowing at the same depth have made a hard, compacted layer of soil. Other soils may have a naturally occuring dense layer as shown in the accompanying illustration.

Soil profile with compacted layer.



If the soil surface is not sealed by the splashing of large raindrops, some soils allow water to penetrate very rapidly. Other soils may do so much more slowly as indicated below. If possible, get to know the rate of water flow or penetration into the soil that you work with.

Classes of soil permeability.

Classes of soil permeability (KLAS-KLAS PERMEABILITAS TANAH) (4)

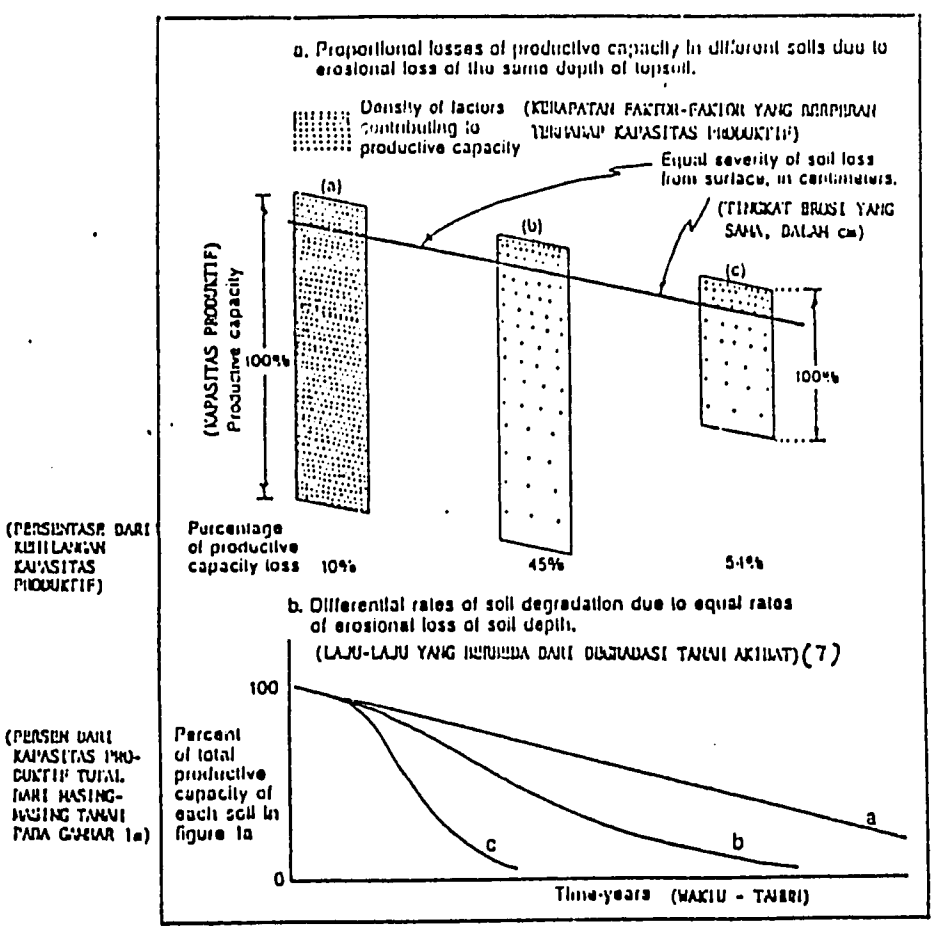
(DESKRIPSI) *Description*	(LAJU ALIRAN) *Rate of flow**	*US Symbol*	*Philippine Symbol*	*Rhodesian Symbols used in field coding*
Very slow	less than 0·5	1	1	1
Slow (LAMBAT)	0·05 to 0·20	2		
Moderately slow	0·20 to 0·80	3	2	3
Moderate (SEDANG)	0·80 to 2·50	4		
Moderately rapid	2·50 to 5·00	5	3	5
Rapid (CEPAT)	5·00 to 10·00	6		
Very rapid	over 10·00	7	4	7

* The rate of flow in inches per hour through saturated undisturbed cores under a head of ½ in. of water.

It has been shown by many people that good crop management, and good land husbandry reduces erosion. A well fertilized field not only produces more yields for the farmer but also developes a larger root system and more top growth, with more plant residue material to leave on the surface. This protects the soil from rainfall damage and also increases the organic matter in the soil which in turn not only increases soil fertility for the next crop but also increases water infiltration. A healthy growing crop, as mentioned above, grows quickly to give quicker soil protection from heavy rainstorms during the early growing season.

If a farmer wishes to try some ideas, such as mulching, to protect his soil from rainstorms he may then wish to treat his most critical soil first. For example, if part of his field has very little top soil left, as in soil "C" in the following illustration, he will treat this soil first because it becomes worthless once the top soil is removed. Soil "C" will be worthless in a very few years unless action is taken.

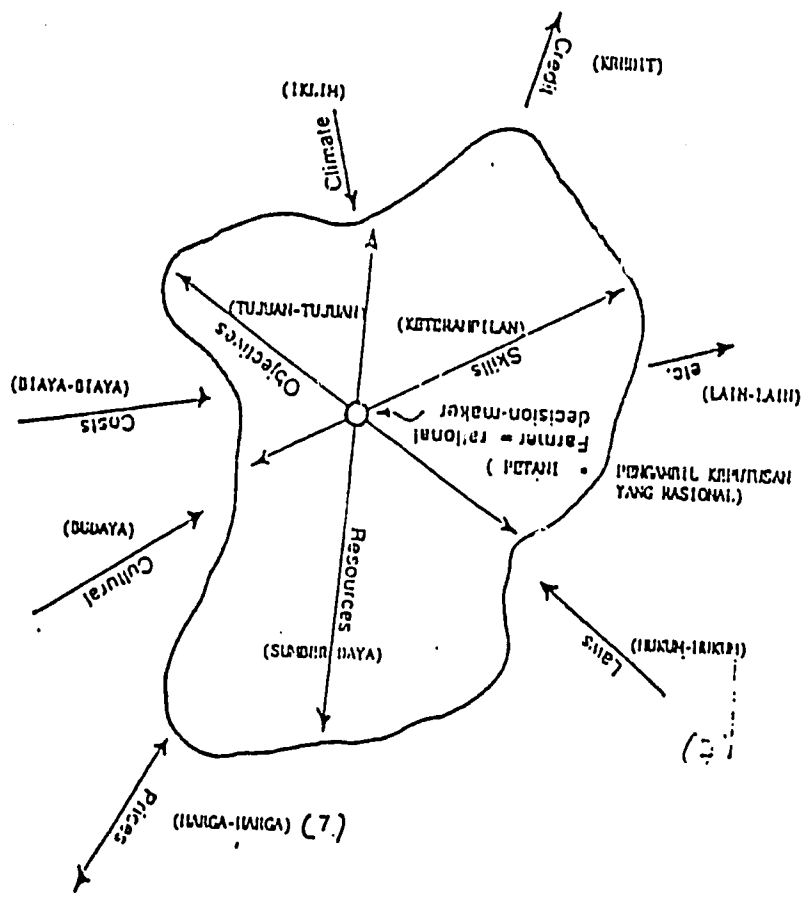
Proportional losses of production capacity in different soils due to erosion losses at the same depth of soil.



Remember that the poorer farmer on marginal soils will not want to take many risks. But if he can see that he can increase his yields by conserving water, he will also conserve his soil in the process. Mulch on the surface will increase the rate of water entering the soil so that crops will have more moisture.

There are many factors which influence a farmer's decision making. If, given the facts, so that he or she believes what is said, then this knowledge becomes part of his skills, and he will usually make the right decision. When any crop production plan or farmer education program is planned, it will be much more successful if many farmers ideas are listened to carefully. Programs which are planned from the "bottom-up", and not from the "top-down" are proven to be the best for the farmer.

Rational decision making.

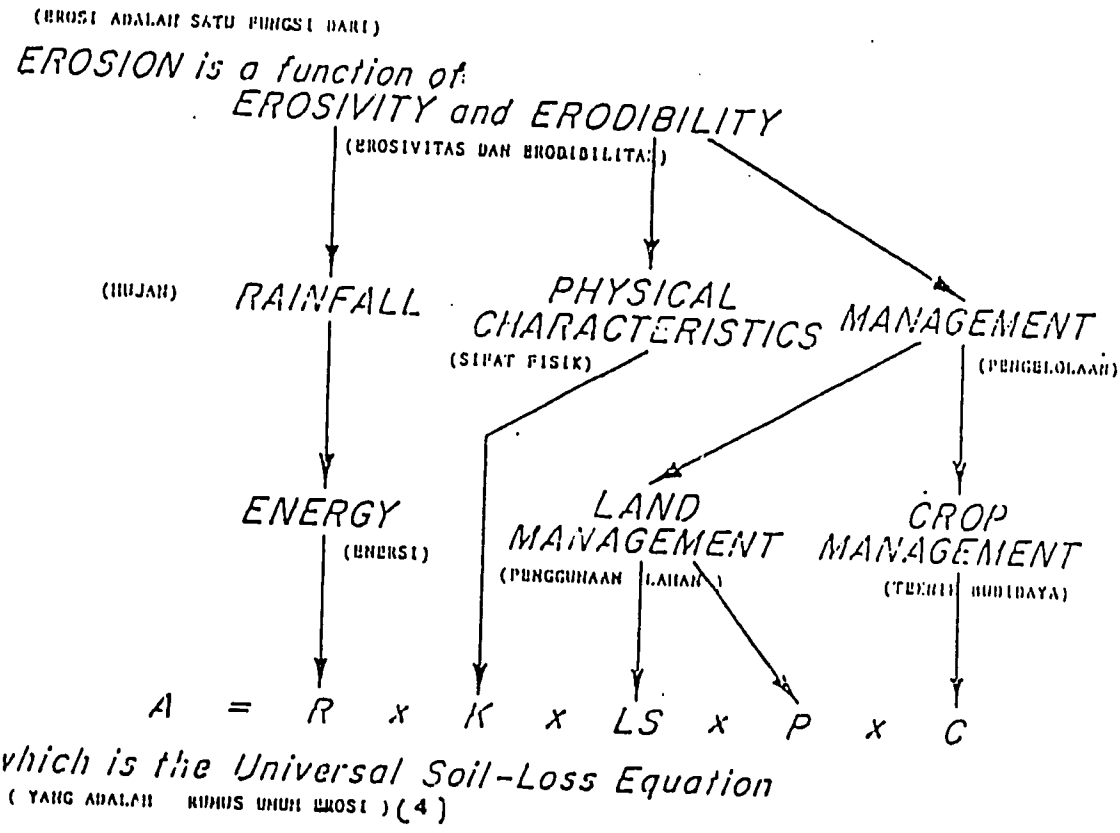


The Universal Soil Loss Equation is given below. It was developed by U.S.D.A. soil research scientists in the 1950's from data accumulated over 20 years from 28 experimental stations which had collected soil erosion and water runoff data from research plots. Actually, data from more than 10,000 plot years of work has been involved in developing this equation.

By using a newly developed computer at Purdue University, Wischmeier (1955-1958) was able to develope the equation below:

A = Erosion
R = Erodibility of rainfall
K = Erosivity of a given soil
L = Length of slope
S = Percent slope
P = Land management factor regarding conservation practice (contour plowing, plantings etc.).
C = Crop management (type of crop, fertility rates, planting dates, cropping systems etc.)

UNIVERSAL SOIL LOSS EQUATION.



In the United States the USLE has been used very successfully for predicting soil losses for different crop management and soil management practices.

The rainfall simulation equipment which was developed by the U.S.D.A. has also allowed the collection of data needed regarding soil and crop conditions not included in the 10,000 plot years studies on experiemental field stations.

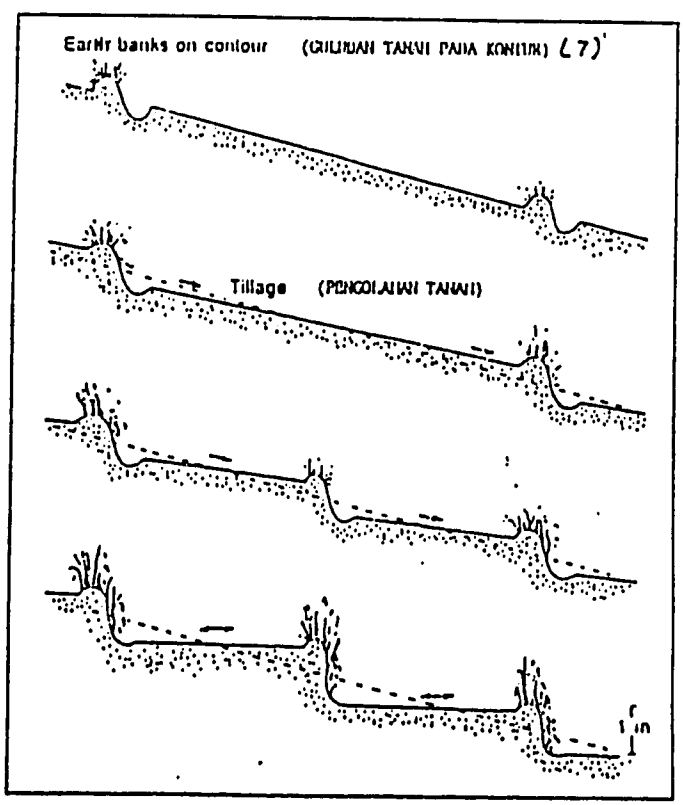
Although we will not discuss the equation in detail in this brief review, it is a very useful tool in the U.S.A. and, with certain assumptions made for tropical rainfall and tropical soils, it can be useful here. It may be, in the future, even more accurate if a portable rainfall simulator is used to obtain the necessary data corrections on certain soils and crop conditions in Indonesia.

Terracing.

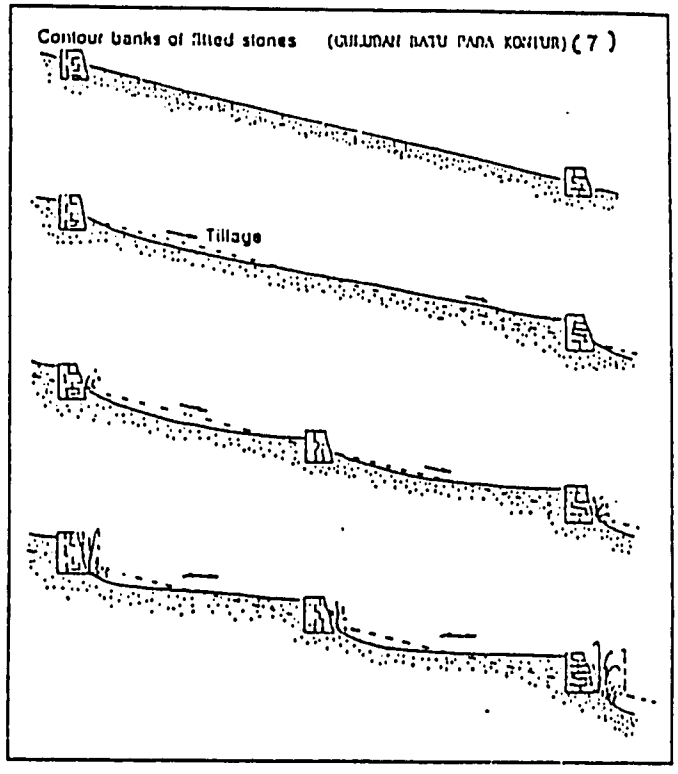
Bench terraces are extremely useful for most slopes if soil conditions are suitable. If, however, the soil is shallow and the sloope is relatively steep, bench terraces are not suitable. In that case some form of alley cropping should be used. Bench terraces are also very expensive to construct. Ansoil scientist in East Java stated that it required 3 man years to construct bench terraces over one hectare of relatively steep sloping ground

If the farmer does not have the money or labor to build bench terraces, or for other reasons desires a less expensive terracing system, then one of the three following suggestions might be feasible. All three systems have contour stone rows, grass/trash/legume hedges or low earthen bunds with grass established on the top and sides. If neccessary, additional banks can be added as shown in the 3rd and 4th rows of the contour banks of the lifted stones shown below. These systems are suitable for more gentle slopes.

Earth banks on contour.

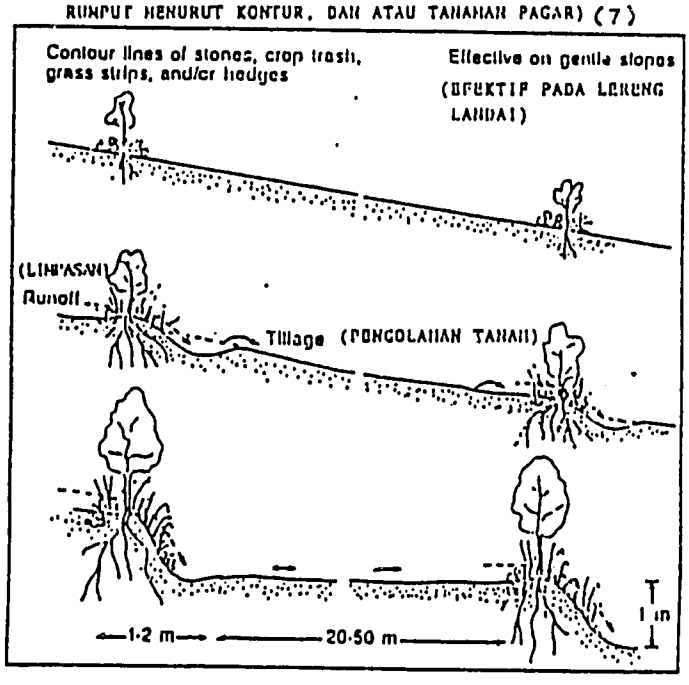


Contour banks of fitted stones.



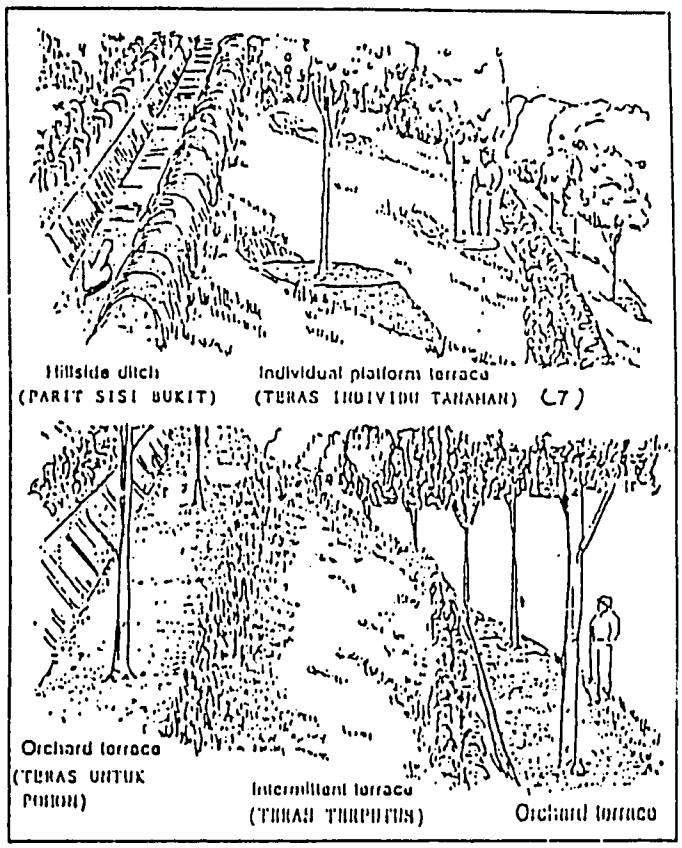
Contour lines of stones, crop trash, grass strips and/or hedg

(BARISAN-BARISAN BATU, SISA TANAMAN, RUMPUT MENURUT KONTUR, DAN ATAU TANAMAN PAGAR) (7)



On very steep slopes where tree or hedge crops are used, of the suggestions in the following illustration may be of us

Orchard terraces.



As has already been mentioned above, if other crops are also to be grown on steep slopes, then some sort of alley cropping should be used. Much good research has been done on alley cropping in Indonesia. Anyone interested should review the AARD literature and consult with researchers from agricultural research stations. One extremely good legume hedge on contour I have observed to be doing very well at two locations at about 2 years of age, and even on acid soils is Flemingia congesta [Flemin macrophylla (Willd.) Merr.]. When mixed with grass it is also a good ruminant feed. In the terraces I saw, it was planted in two rows only a few centimetres apart. and planted closely in the row in a staggered fashion.These mature plants, with root and stems closely interwoven, were doing an effective job of holding the soil. One farmer was feeding 50% cut grass and 50% legume leaves with good results.

There are many types of conservation banks or high-wall contour terraces.

The important thing about choosing a type of terrace is to know precisely the purpose of the type that you choose and what the needs of the farmer are. All types are used for water management but some are for different purposes than others. The farmer's need may be to encourage infiltration, or it may be to capture the water and hold it. Another purpose might be disperse thin, non-erosive flows and spread them out so that no rills or gullies are formed. Another purpose might be to form guides around a slope to a discharge area. In deciding which type of terrace to use and the type of bank to construct, the farmer must consider the slope of the land, the needed length of the slope, the type of farming to be practiced, and the means of construction to be used for the bank. The design of the form of bank is based upon sound, well-established hydrologic and hydraulic principles which are described in text books (see, for example, Hudson).

Storm diversion drains, cut-off ditches or diversion contour banks are designed to cut off surface runoff from higher ground and to keep it off of lower ground. These are open channels with a bank on the lower side. Grasses can be planted on the uphill edge of the ditch to trap the soil and let the water from the runoff go into the ditch.

On gentle slopes, contour terraces or graded channel terraces on slopes under 8% in use with mechnized farming, the banks are built low and wide so farm machinery equipment can pass over them.

For construction of any type of water way, consult a text book, or if a local soil scientist or an experienced engineer is available, consult them for advice. This same recommendation applies to choosing and constructing drop structures and major water ways.

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