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AGROMETEOROLOGY IN RELATION TO THE CONTROL OF SOIL EROSION

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1. INTRODUCTION

Many people consider soil erosion to be a natural phenomenon which is going on slowly and continuously over the whole land surface of the world and that erosion following man's attempt to improve the productivity of land is merely an acceleration of this process. In fact, there is much evidence to show that he natural erosion of landscapes has been mainly due to a series of catastrophic events which occur from time to time and that between such events there are periods of relative stability. Accelerated soil erosion has occurred where man's activities have created conditions similar to those which could have resulted natural but much less frequently from catastrophic events such as climatic change or geological upheaval. Soil erosion is not necessarily an inevitable consequence of man's use of the land and can be avoided.

Primitive man created no problems of soil erosion. He was unable to change his environment to any significant extent and he lived within it in much the same way as any other animal. But man's ability to modify his environment has increased and today there are the means for making drastic changes within and incredibly shore space of time.

Before man had the ability modify his environment there existed many different kinds of landscape or ecosystems each of which has recognizable character due to the particular combination of climatic, topographic, soil and biotic conditions.

Within each ecosystem there was an endemic population of plant and animal species which represented those from the available species that were best able to live in association and competition with each other under the prevailing climatic, topographic and soil conditions. The relative numbers of individuals of each of the species varied from season to season and from year to year, but these changes tended to oscillate about a mean condition. These systems had a dynamic stability which was maintained unless there was some dramatic event such as geological upheaval or a major climatic change.

Provided no catastrophic event occurred, these ecosystems over long periods went through evolutionary changes known as ecological succession whereby sequences of plant and animal communities followed each other along with changes in soil development. In this succession there was a trend toward a maximum sustained biological productivity from those species of plants and animals available during the period of development.

Man changes ecosystems because the maximum sustainable biological productivity is either not enough or not what he wants. In making these changes man has ahs considerable success, but in places land has been destroyed and productivity has declined because he failed to understand that unless the new system of land use and management provided a dynamic stability, the system itself reacted to establish a new balance. It is this reaction which leads to erosion and in many parts of the world whole ecosystems have been destroyed and the productive capability reduced to a level from which it is exceeding difficult to achieve satisfactory reclamation.

When man alters an ecosystem to improve its productivity he clears the land of vegetation, cultivates, burns and grazes with increased numbers of stock and, in so doing, changes the hydrology and exposes the soil to the effects of sun, wind and rain. This leads to soil erosion and some people have sought an answer by means of soil erosion control. But this is a negative approach because it implies that whenever land is modified by a man to attain increased productivity, soil erosion is an inevitable consequence and it must be controlled.

The concept of soil conservation is much more positive and rational because it is based on an understanding of ecosystems, the nature of land and its capabilities, and it is directed toward determining how such ecosystems can be changed to provide increased productivity whilst still maintaining a dynamic stability so that erosion will not occur.

Soil conservation embraces the need for controlling erosion which has already occurred, the reclamation of land already damaged by soil erosion, but more importantly the determination of suitable systems of land use and management for different ecosystems so that erosion will not occur.

2. PHYSICAL CAUSES OF SOIL EROSION

Soil is subjected to the effects of wind and water when land is cleared and cultivated, or when the vegetation is destroyed either by overgrazing or by inducing conditions unsuitable for vegetation such as high salinity.

The action of wind or water on bare soil leads to three phenomena, namely detachment of soil particles from the surface, their transport b these fluids and their subsequent deposition. Whether these phenomena occur, and the extent to which they occur, depends on the energy available in the moving fluid in relation to the texture and structure of the soil, the nature and roughness of the soil surface, the size distribution of the detached particles and the relative densities of the soil material and the fluid.

Fluid flow at a steady velocity over a smooth surface will be laminar except for a thin layer close to the surface where the drag resistance of the layer causes shearing of the fluid stream and the initiation of eddies to give turbulent flow. The energy of this turbulent flow enables detachment and transport of soil material. Deposition occurs when the velocity and turbulence of the fluid is diminished and there is insufficient energy to maintain the load.

Although soil erosion by wind or water is due to a common phenomenon, the movement of fluids across the soil surface, there are significant differences in the mechanics of the two actions. This is due to the great difference between the ratios of the densities of each of the two fluids to the material being transported. Taking buoyancy into account, the ratio for air and quartz sand is about 1 to 2000, but for water and quartz sand, it is only about 1 to 1.65. Because of this difference the relative importance of surface creep, saltation and suspension as means of transporting detached material is different for water and wind erosion.

2.1. Methods of Transport

2.1.1. Surface Creep

Surface creep is the rolling movement of particles along the surface. This is initiated when the pressure of the moving fluid is able to overcome the gravitational and frictional forces tending to keep the particle at rest. This is much easier initiated by water than by wind because the density of the fluid is about the same order as that of the material to be moved. In wind erosion, single grains or aggregates of more than 3 mm. diameter are not moved by winds of 30 m. p. h. at 6 inches above the surface. On the other hand, water velocities of 5 m. p. h., which is about the order of magnitude of many flood flows in streams, can initiate the movement of large boulders as surface creep or bed load.

2.1.2. Saltation

Saltation is the movement of particles by a bounding action. Particles leave the surface in an almost vertical upward motion whence they are carried forward and downward to again reach the surface, the angle of impact being much more acute than the angle of departure. Saltation is much more important in wind erosion than in water erosion. Not only is it the means whereby most of the material is moved but the low angle of impact and high velocity of the grain returning to the surface initiates further movement of large grains and of small material which would not be moved at all except for this impact effect. It is doubtful whether the vertical take-off by grains occurs in water erosion, because of the lower velocity of the fluid. In wind erosion the rolling of the grains, the higher velocity and the steeper velocity gradient near the surface apparently give rise to the conditions under which the Bernoulli effect becomes operative.

2.1.3. Suspension

Suspension is the movement of soil material in the body of the fluid. This can occur only when the turbulent energy of the fluid is sufficient to overcome the settling velocity of particles due to gravitation. Stokes Law expresses the settling velocity of a particle in relation to its radius, the viscosity of the fluid and the densities of the particle and the fluid.

$$v = \frac{2(\rho_s - \rho_f)}{9\mu} g r^2$$

v = settling velocity of the grain
ρ_s = density of soil grain
ρ_f = density of fluid
g = acceleration of gravity
μ = coeff. Of absolute viscosity

When the relevant values for soil and for air or water are inserted in the equation there is a tremendous difference in magnitude of v for any given value of μ. Consequently movement of soil by suspension is not such a significant occurrence in wind erosion, but it is the major means of moving soil in water erosion.

In wind erosion, material moved by suspension is usually of grain size which would not normally be moved even by a high wind velocity but once stirred up by saltation, it is carried away from the area and may be deposited hundreds of miles away.

In water erosion there is a constant interchange of suspended material except that of colloidal size. Gravitational settling in still water would produce a concentration gradient from top downward and so in turbulent conditions eddies transporting water upward to a given layer carry more suspended material than do those moving downward. This transportation in suspension is a continuous process of scouring and settling out. If the two processes act at equal rates, the bed configuration is unchanging with time and suspension conditions are in equilibrium. If velocity of flow and roughness of bed are such that turbulent transfer exceeds gravitational settling, then the bed or surface is being scoured or eroded. Conversely, if gravity predominates, sediment is being deposited on the stream bed.

Obviously the velocity and turbulence of the sir are major factors but density as affected by temperature, pressure and modify and the viscosity could have an effect.

The ground conditions which must be considered are roughness, degree and kind of vegetative cover, obstruction s of various kinds, temperature and the general topographic features.

Soil properties of significance are structure as affected by texture, organic matter or line; the specific gravity of the particles and the moisture content of the surface.

2.3 Water Erosion

The important factors vary depending on whether the type of erosion being considered is that which occurs on a field or that which occurs in gullies and streams. On bare fields one factor of great significance is the energy of the rainfall itself. This is governed by drop size which according to Stokes Law determines its velocity, the intensity and the duration. The energy of the rainfall has significance in whether soil is detached or moved by raindrop splash, and whether it has a dispersing effect on the soil to bring particles into suspension or a compaction effect, both of which will reduce the soil's ability to infiltrate, and will smooth the surface so that higher water velocity can occur.

Even with high rainfall energy some soils are resistant to such effects. The degree of resistance to these effects or the stability of the soil, depends on the texture, the structure both with respect to the size distribution and stability of aggregates, the surface condition of the field and the moisture content of the soil at the onset of the storm.

3. AGROMETEOROLOGY AND SOIL CONSERVATION

3.1 Climate

Because soil erosion results from an upset of the dynamic balance of ecosystems, a good knowledge of the incidence, range and variability of the various elements, which collectively determine climate, is vital for assessing the potential, stability and hazard in developing various ecosystems. Climate is the independent feature of an ecosystem and to a large extent determines its nature. This is because the other features of the ecosystems such as the soils and their depth, structure and nutrient status; or the numbers and kinds of plant and animal species; or the nature of hydrologic cycle are dependent on and determined to a great extent by climate. But it is the collective effect of these features which gives an ecosystem its character and determines the dynamic stability which may be upset if main imposes changes. The degree of ease or difficulty with which the stability of an ecosystem may be changed is usually governed by its climate.

In climates favourable for plant growth there is usually a wide range of species and any alteration by man usually leads only to a change in species composition rather than complete destruction of vegetative cover. In fact some ecosystems are so resilient in this respect that it is almost impossible for man to convert them to agriculture. This is because there is a constant battle with regrowth of various species which although not originally the dominants have found the conditions created by man, together with lack of competition from the original dominants, an ideal environment in which to thrive.

On the other hand ecosystems occurring in extreme climates as for example, arid zones, alpine areas or exposed coastal areas have specialized vegetation in which there is a limited number of species. These plants have been able to adapt themselves to these kinds of situations, and if they are removed, or damaged by a grazing pressure to which they have not been accustomed and so gradually die out, there is nothing to take their place. Not only are these ecosystems potentially unstable but when the soil is exposed in such ecosystems, there are conditions most conducive to erosion.

In semi-arid or sub-humid climates with marked seasonal climatic conditions, the hydrologic balance of the system is vulnerable. By changing the vegetation from forest to grassland there can be significant changes in hydrology which alter the dynamics of the ecosystem to provide too little water in some parts of the season and too much in others. Situations of this kind are common in various parts of Australia and many examples of damage can be seen. Gully and tunnel erosion, and salting in some parts of unirrigated area, are all manifestations of such instability in Victoria.

Climate can be looked upon as the major governing factor in determining land use to achieve conservation – that is the nature of land use and management which can be impose on an ecosystem to give higher productivity on a sustained basis. On the other hand, weather or the day-by-day phenomena, will determine to what extent erosion might occur if the new system does not provide stability. These weather events are important in determining what methods of erosion control should be used and how they should be designed.

3.2 Specific Weather Phenomena

3.2.1 Rain

The important features of rain events for erosion control are the storm size, intensity, duration and the time of the year when significant storms can occur in relation to the land use being practised. These are all important features which affect the overall hydrology of the system and determine the basis for designing erosion control works of various kinds and also flood mitigation schemes.

The relative significance of different kinds of events is relation to the overall climate. For example in a winter rainfall climate like Victoria, high intensity summer thunderstorms can do much local damage but they rarely lead to widespread damage from flooding. The most damaging floods and the greatest erosion usually occur in conjunction with persistent rain of long duration falling on saturated catchments in the wet season.

In some parts of the world spring rains falling on frozen soils provide a situation for the greatest runoff and erosion from catchments leading to major floods in river systems.

3.2.2. Snow

Incidence of snow can be important in some areas. A continual snow blanket throughout the winter is less destructive to vegetation than isolated falls of snow interspersed with freezing and thawing conditions. The latter condition sometimes happens in the alpine areas of Australia and ice crystals associated with surface freezing break up the surface soil into a condition which makes it easy to be blown or washed away.

Snow avalanches in some countries do considerable damage. The incidence of the snowfalls can have a bearing on whether avalanches will occur. A heavy snowfall onto a previously frozen snow surface provides a condition in which the top layer can move easily downslope.

3.2.3 Wind

The important aspects are the individual wind events and the significant parameters are strength, duration, direction, variability pre-storm moisture conditions, humidity and the times of the year when storms are likely to occur. From these attributes it is possible to assess for any given system of land use in a particular locality whether there shall be erosion at all on some soils or whether there will be damage to the vegetative cover to an extent which will allow erosion to occur ear some subsequent time.

4. EROSION CONTROL AND SOIL CONSERVATION

Soil conservationists are confronted with three tasks, namely the control of existing erosion; the reclamation of areas damaged by erosion, the determination of appropriate systems of land use and management for different kinds of country so that erosion will not occur again.

In these tasks, aspects of agrometeorology have varying degrees of significance.

4.1 Conservation

The determination of appropriate systems of land use and management for different types of land requires a good knowledge of the features which together give character to the land – namely the climatic conditions including the likely incidence of particular weather phenomena, the topography, the soil and native vegetation. Provided the soils and slopes are satisfactory, the climatic conditions determine what can be done with the land. In considering the climatic conditions, one is confronted with two aspects – the gross climate and the micro-climate, the latter being interpreted not as the micro-climate at the surface under the existing vegetation but rather the micro-climate which will exist under the propose form of land use.

In the interpretation of the gross climate one is concerned with considering the combined moisture and temperature conditions and their suitability for the growth of different useful crops, pasture species and animals; and also whether the prevailing conditions will aid or limit the growth at specific times of the year or affect the numbers of other plant and animal species which may provide competition; or finally whether the conditions will enhance or diminish the incidence of plant or animal disease.

For the purpose one is concerned with the amount of precipitation, its distribution throughout the year, its reliability of occurrence throughout the year and from year to year, and its usefulness as judged by the prevailing conditions of temperature and humidity which determine the potential evapotranspiration.

The consideration of these climatic features on an annual basis provides inadequate information. The minimum requirement is for both rainfall and temperature data to be available on a monthly basis and for some considerations, weekly periods would be much better. Studies of the variability of the monthly means and the probability of departure from the means enables a rational understanding o the climatic advantages and disadvantages being encountered and their assessment in relation to the plant and animal specie which could be used in a system of land use and management.

In addition to the assessment of general climate form this data, it is essential to interpret it in relation to local topography and aspect where there are likely to be drier and wetter sites in which the potential for different uses could be vastly different.

4.2 Erosion Control

From the principles discussed earlier it is evident that the major difference between wind erosion and water erosion is in the means of transport of material from the area. In wind erosion the major movement is by saltation and if this could be prevented there would be little soil movement. On the other hand the major movement of soil by water is in suspension and the effectiveness of this depended on turbulent flow.

But these effects can only occur when the system of land use and management requires the soil surface to be unprotected by vegetation for some part of the year. In these circumstances specific erosion control devices must be applied in certain climatic and topographic regimes.

4.2.1. Water Erosion

For the control of water erosion these are directed toward slowing down the movement of water over the soil surface and the improvement of the infiltration capacity of the soil to absorb water where it falls. This is achieved by contour works which may range from merely cultivation on the contour to more sophisticated conservation works such as graded banks and waterways or even bench terraces. There are various soil management techniques which can be used to improve infiltration and prevent surface sealing dur to the effect of raindrop action. Surface management will include various tillage techniques, mulching with residues from a previous crop, the use of vegetative cover in rotations both to give protection and to maintain the hydrologic balance as close as possible to the original. Surface management techniques may be used either alone or in conjunction with the contour principle.

4.2.2 Wind Erosion

For the control of wind erosion, saltation can be prevented if the layer of zero wind velocity at the surface is made as thick as possible. For this reason increased surface roughness is desirable and this can be achieved by tillage techniques to provide a cloddy structure, ridging by means of furrows, the retention of crop residues as a mulch or even the growing of some vegetation to give protection at critical times of the year. Shelter belts have been used but these are not particularly successful in broad-scale farming because their effectiveness only extends out from the windbreak to a distance of about 10 times the height of the shelter belt.

It is possible to determine for different kinds of soils the minimal threshold wind velocity at which erosion will occur. From this a knowledge of the probable incidence of such winds for various times of the year will assist in designing rotation and tillage programmes to reduce the vulnerability of the area to erosion.

4.2.3 Flood Protection

In the design of water control device, it is essential to have information on which to base the capacity of the various structures. For earthworks the capacity is normally based on the maximum storm expected once in 10 years, but for more inflexible concrete structures, the design is based on the once in 50 year storm. Works for flood protection are based on particular flood probabilities, the particular flood frequency chosen being related to the cost in relation to the damage which accrues from floods of particular frequencies.

5. SIGNIFICANCE OF AGROMETEOROLOGY IN CONSERVATION

Agrometeorology is a significant facer of soil conservation. Its main value lies in those aspects which are of obvious significance in the advancement of agriculture, animal husbandry, forestry and water conservation and use.

Special aspects of agrometeorology of particular value are those which lead to a better understanding of the factors affecting micro-climate and the changes of micro-climate associated with the modification of natural ecosystems to improve productivity.

For erosion control, increasing amounts of data concerning the probabilities of occurrence of particular kinds of weather events will provide a better basis for assessing possible hazards and for designing control measures to combat the ill effects which could arise.

Because problems vary from country to country, agrometeorologists should bear in mind the basic principles of soil conservation and erosion control, but work in close liaison with those actively engaged in this field for the definition of useful specific problems.