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Soil Tillage in the Tropics and Subtropics

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R. Krause, F. Lorenz, W. B. Hoogmoed

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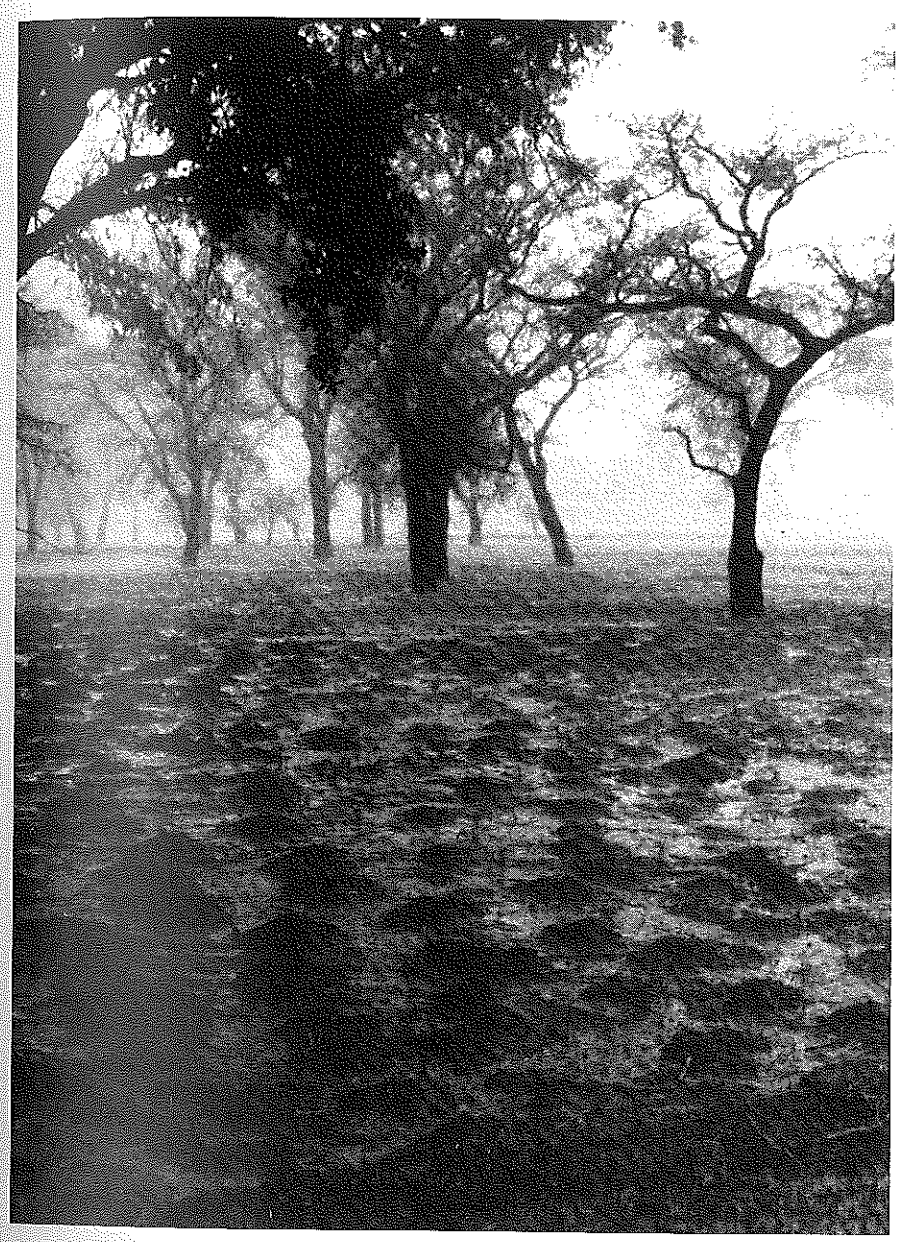
3.0 CLIMATE AND SOIL TILLAGE



Climate and weather have a considerable effect not only on the cultivation of plants but also on the necessary or possible technologies and techniques.

Climate and weather particularly affect:
- the soil water balance throughout the year, both during and between vegetation periods;
- the duration of the vegetation period which is limited by water deficits and/or low temperatures;
- the soil temperature;
- the soil (micro)biological and chemical (conversion) processes.

In view of these effects of climate and weather it seems expedient to apply the following division into climatic zones:
- Soil tillage in temperate humid climates;
- Soil tillage in arid (tropical) regions
  - with winter rainfall,
  - with summer rainfall;
- Soil tillage in humid and subhumid tropical regions.

No clear definition of the climatic zones is possible since the site's position in relation to the sea and its height above sea-level may cause considerable deviations from the average characterstics. Figs. 9 and 10 give only a general idea. The aspects of soil tillage when there is a risk of soil erosion will be examined in a separate chapter because this subject is not limited to specific climatic zones.

3.0.1 Literature

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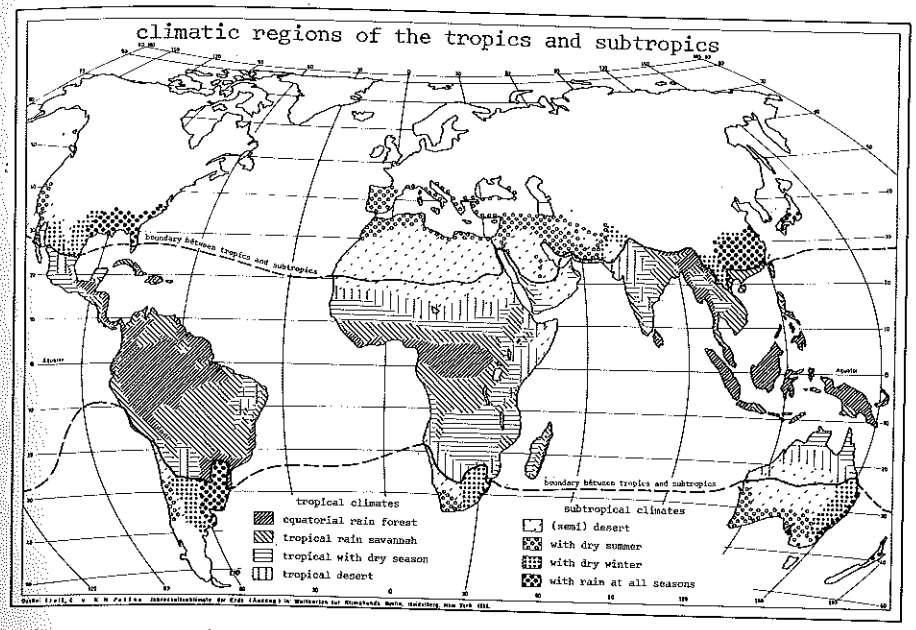

Fig. 9. Seasonal climates in the tropics and subtropics. - Source: Andreae.

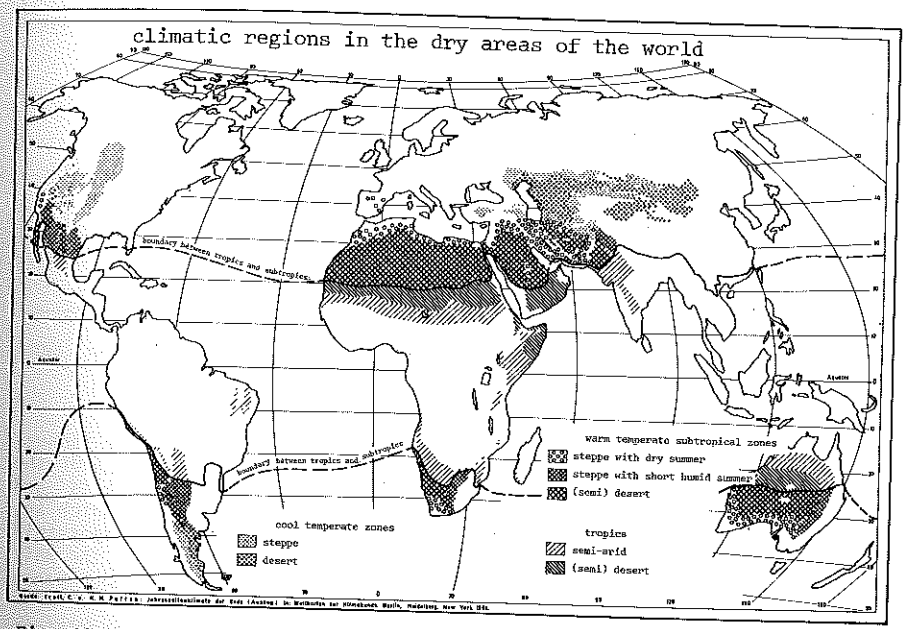

Fig. 10. Seasonal climates in the dry regions of the world. - Source: Andreae.

3.1 Soil Tillage In Temperate Humid Climates

In the temperate zones the vegetation period is restricted by low temperatures and, in some cases, also by insufficient light. During the cooler season the evaporation rate is low and the decomposition rate of organic matter is greatly reduced owing to the relative inactivity of the soil organisms. Frost improves the soil structure to a certain extent.

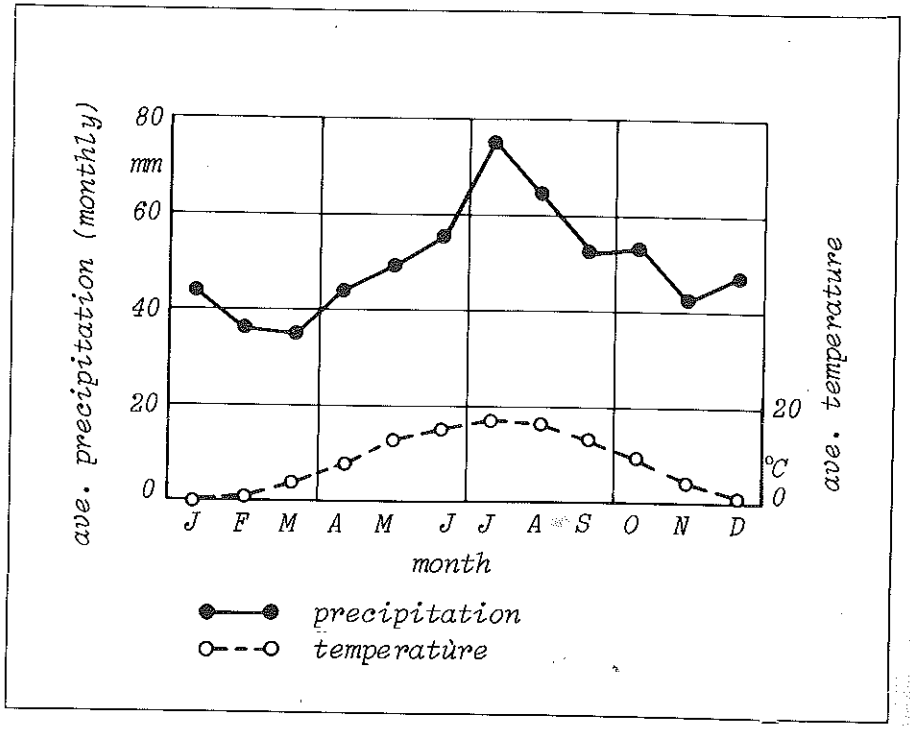

Fig. 11. Temperature and rainfall (monthly averages for Kassel, Fed. Rep. of Germany). - Source: Schreiber.

Temperate zones (Fig. 11) are usually humid in the sense that the annual precipitation exceeds evaporation. So during a large part of the year the soil water descends into the subsoil carrying with it dissolved salts and small soil particles. These particles often form dense layers which are impermeable to water and which plant roots find it difficult or impossible to penetrate. The greater the precipitation and the coarser the soil texture (particle size distribution), the more pronounced this phenomenon will be, especially near the natural boundaries between layers.
The soil tends to have a low pH value under these climatic conditions (acid).

The following soil tillage conditions may exist:
- The time available for tillage operations depends upon the crop rotation but in most cases is comparatively long. Very cohesive soils are an exception. They absorb so much water (low evaporation) that moisture contents suitable for soil tillage occur only very short periods.
- Deep (primary) tillage operations can be performed during and at the beginning of the period of vegetative rest. Owing to the low temperatures the decomposition of organic matter is not markedly increased by loosening the soil and making the oxygen available.
- Damage to the soil structure which may have occured during the vegetation period and harvesting can to a large extent be remedied by deep tillage and frost action.
- Mechanical inversion is necessary to bring the leached small soil particles (clay minerals) and nutrients back to the topsoil. This operation should be performed more frequently when leaching is more pronounced. It is not required so often on cohesive ("heavy") soils.
- Inverting the soil with a mouldboard plough still seems to be the best mechanical means of controlling weeds.
- The extent to which soil tillage can be reduced to save energy and costs and the conditions required for this are still uncertain but are being intensively studied (see Chapter II.10).

3.1.1 Literature

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3.2 Soil Tillage In Arid Climates

Arid climates are characterized by a deficit water balance. The annual evaporation exceeds precipitation as a result of low relative humidities, high temperatures and wind. Most of the infiltrated water may be lost as a result of evaporation.
Rain occurs during limited defined periods in these zones. Humid climatic conditions may temporarily obtain during these rainy seasons. The intensity of the rainfall, the infiltation capacity and hydraulic conductivity of the soil determine whether any excess rainwater will be stored in the subsoil during these brief periods.

Some of the soil water eventually reaches the surface again as a result of evaporation. Dissolved salts are also transported by this water and crystallize on the surface. These climatic conditions may result in the formation of alkaline soils which have a high concentration of salts in the upper layers or on the surface.
The length, intensity and timing of the rainy season or seasons depend upon the geographical location. Considerable deviations from the long-term mean may occur with regard to the incidence and amount of the rains.

Water is the principal restrictive growth factor in arid regions and fallowing is often the only way of producing some kind of water storage system. The yields in these regions are largely determined by the amount of precipitation (Fig. 12); below-average rainfall may result in complete crop failures which not only cause a complete loss of the input of soil tillage, seed and fertilizer but also leave the bare soil virtually without protection against wind and sun, making it extremely susceptible to erosion. Soils in arid climatic zones should be considered for agricultural use only after long-range weather records have been analysed with special attention to the extent and frequency of deviations from the mean.

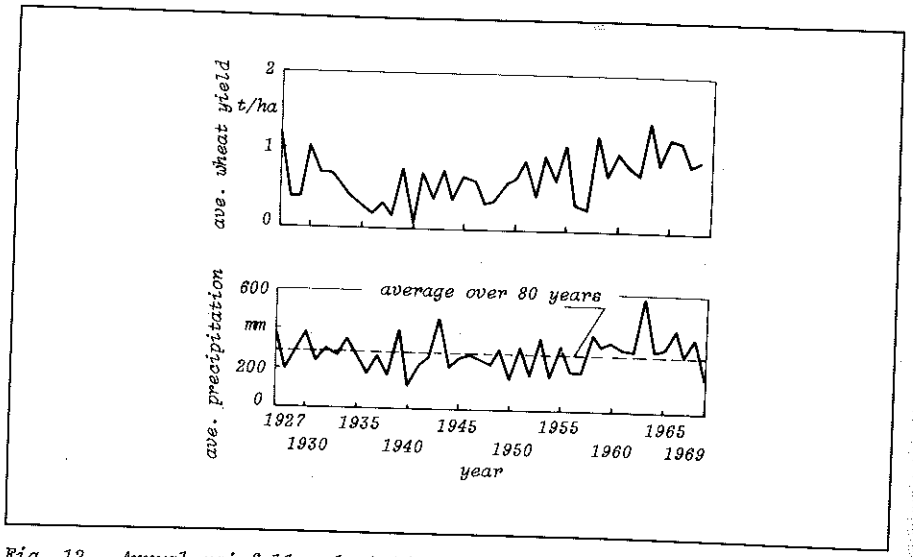

Fig. 12. Annual rainfall and yield of wheat in Western Australia (Yilgarn Shire).

One problem in every arid region is the short time available for soil tillage. Seed should be sown as soon as possible after the rainy season begins to obtain the full benefit of the vegetation period. Every delay shortens the growth period of the crop, because ripening begins anyhow with the dry season, resulting in yield losses and lower qualities. Soil tillage cannot, however, begin until the rainy season starts. If tillage is carried out too early, the soil surface may slake, reducing rain infiltration and causing surface runoff. In addition, the soil can be worked with a relatively low input of energy only during a short period after the first rains because the water content of the topsoil changes very rapidly; when the soil is too dry, it may become "rock hard" and, when it is too wet, it may not be workable or trafficable.

It is frequently difficult to predict the effects of soil tillage because the mechanical manipulations affect not only the physical but also the biological and chemical characteristics. For example, loosening the soil also increases the air and oxygen supply and, with high temperatures, this increases the decomposition of organic matter by organisms living in the water and soil. This will, in turn, cause rapid deterioration of the soil's capacity to retain nurtrients and water. If the organic matter content is reduced, the soil's mechanical properties will also diminish.

For optimum results, the short period of time available for tillage requires a high standard of efficiency. When draught animals are used, they are particularly weakened by malnutrition at this period and cannot produce the necessary strength. Generally speaking, therefore, if plant production is to be increased and stabilized in these regions, motorized traction should be available.

Soil tillage in semi-arid climates should have the following objectives:
- total intake of the rainwater by the soil (high infiltration and water holding capacities);
- reduction of evaporation;
- weed control (weeds compete for water with cultivated plants);
- reduction in the decomposition rate of organic matter;
- control of soil erosion.

The methods required for achieving these objectives differ to some extent for regions with winter and summer rainfall.

3.2.1 Soil Tillage In Winter-Rainfall Areas

Winter rainfall areas are those in which the rainy season and thus the main vegetation period occurs during the cooler winter months (Fig. 13). Typical examples of this climate are found in the Mediterranean region. There is less evaporation and weed growth during the cool period than in the summer-rainfall region. In some parts of this region (southern Europe, North Africa) the temperatures may be so low that they affect the development of cultivated plants.

The intensity of the rainfall in the winter-rainfall areas is comparatively low and the risk of soil erosion by water is less than in summer rainfall areas. Lenghty dry spells - not uncommon at the beginning of the rainy season - are less dangerous than in the summer-rainfall region owing to the lower evaporation rate.

In view of the mean precipitation of 250 mm during the vegetation period cereals can be grown with suitable cultivars and water-saving farming systems. These require a sufficiently long vegetation period and deviations of less than 100 mm from the mean precipitation.

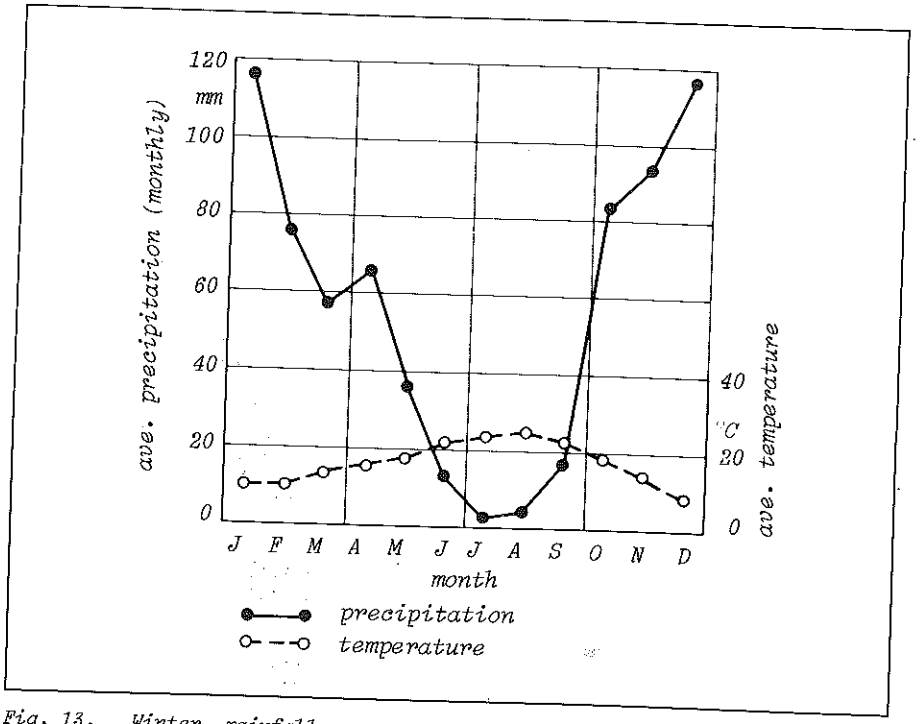

Fig. 13. Winter rainfall area; Monthly averages of temperature and rainfall in Alger, Algeria. - Source: Schreiber.

With low rainfalls the soil is rarely moistened to depths of more than 30 cm and so shallow soil tillage is recommended. The soil surface must be sufficiently loosened to absorb the rainwater.
Soil tillage in regions with greater rainfall and heavy soils causes problems. These soils are subject to considerable hardening during dry periods. After the rains have started, they are still difficult to till and are almost impassable. Under these conditions the period during which they can be worked is extremely brief.

Primary tillage should be carried out shortly before or at the beginning of the rainy season. Harvest residues can thus provide at least some protection for the soil. Loosening the soil at the beginning of the dry season could increase the risk of wind erosion. Tillage should aim at creating a coarse aggregated surface. It is hardly necessary to invert the soil since this could cause water losses when the soil is already moist. Implements with discs, heavy tines or steep mouldboards with a limited inverting effect are suitable for primary tillage. Mouldboard ploughs should be moved slowly to avoid excessive pulverization. If conditions are favourable, a second tillage operation before sowing may be unnecessary or

combined with the sowing, in which case weed control by herbicides will very probably be required.
With the traditional method seeds (of winter cereals) are broadcast when the soil is moist enough for tillage; ploughing is then also carried out to cover the seeds. Weed control is poor.

Deep tillage during the dry season using mouldboard or chisel ploughs or subsoilers has become customary in many regions with high-input agriculture. This system has the advantages of timeliness, better weed control and improved soil structures. Deep tillage (50 - 70 cm deep) forms large clods which are resistant to wind erosion. Weed-roots, soil pathogens, etc. will die when these clods dry out completely. The clods will disintegrate slowly by natural weathering and under the effect of the first rains. Seedbed preparation causes no difficulties if the weather pattern is favourable; special equipment is used when clods have to be broken up. This system requires a high energy input and special equipment. The tractive power needed for ploughing operations in clod-forming soils may be 2 to 3 times more than for soils in temperate regions. Consequently, intervals of 4 to 5 years are normal, with shallow tillage in intermediate years.

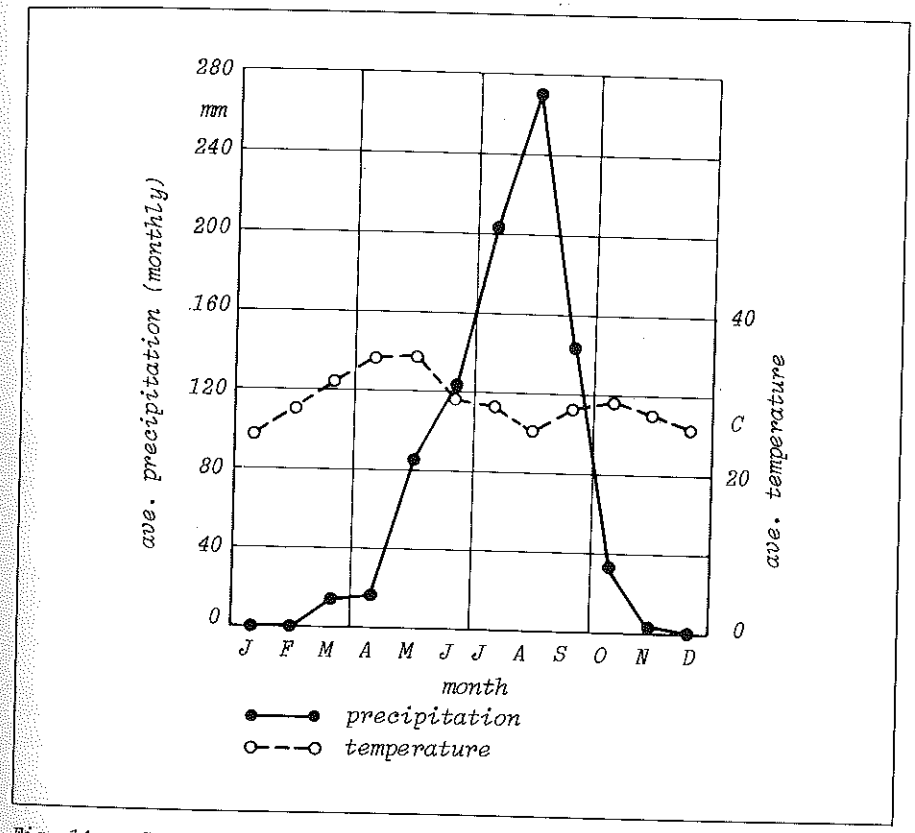

Fig. 14. Summer rainfall area; Monthly averages of temperature and rainfall in Ouagadougou, Upper Volta. - Source: Schreiber.

3.2.2 Soil Tillage In Summer-Rainfall Areas

The precipitation in summer-rainfall areas occurs during the hot season (Fig. 14), mainly in the form of thunderstorms. The rainfall intensity is very high during those storms. The largest raindrops have a high kinetic energy (impact). On uncovered soils this causes the destruction of the aggregates and compaction or crusting of the surface which prevents absorption of the large volumes of water, producing a serious risk of surface runoff and soil erosion. In the case of loamy sands in the Sahel region it is estimated that 25% or more of the annual precipitation may be lost as runoff.

Strong weed growth can be expected owing to the high temperatures which occur right at the beginning of the vegetation period. The potential evaporation is also high. Dry spells may be very critical for newly-sown fields or young crops.

The total annual precipitation is usually greater than in the winter-rainfall areas; 500 mm is considered the minimum requirement for growing millet, one of the cereals with the greatest drought-tolerance.

So in these regions the objectives of tillage should be:
- Water conservation,
- To permit sowing as early as possible in the rainy season. It has been demonstrated that the yields in these climates are closely related to the time of sowing. Delays of a few days or a week can reduce yields by 10 - 100%. An early soil cover also helps to prevent erosion;
- To create stable soil aggregates on the surface which can withstand the impact of raindrops;
- To form mulch from the plant residue which acts as a mechanical barrier to soil movement and slows down runoff water. The soil should be turned carefully, perhaps at longer intervals, because plant residue may be buried too deep so that it can no longer act as a mechanical stabilization agent for the soil surface. Inverting the soil also increases aeration in the tilled layer, which may accelerate the decomposition of the organic matter and cause water losses. On the other hand, the deeper the material is placed, the slower the decomposition rate;
- To improve infiltration and reduce evaporation losses by means of a second operation (opening-up the sealed soil surface) before the soil is entirely covered by crops;
- To preserve or, possibly, increase the amount of organic matter by combined farming operations. In view of the rapid mineralization process, plant residue should be worked in shortly before sowing.

While a tillage system should preserve organic matter, the amounts actually produced by crops are very small, especially in regions with annual rainfall of less than 1000 mm. The decomposed quantities are usually equal to or more than the volumes produced.

Disc implements which mulch in the plant residue without disturbing or inverting much of the soil may be suitable for primary tillage in low-density soils, but only under conditions where there is no erosion risk. Disc implements may produce less permeable layers in soils which are susceptible to erosion. Implements with tines or chisels are recommended when the soil has to be loosened. The operation will be satisfactorily carried out only if the soil is not too moist and below the lower plastic limit (see Fig. 4) because it should be broken up and not deformed. The surface can be tilled with shallow-working weeder blades, duck-feet or rotary hoes. The rotary hoe is particularly suitable when there are large amounts of plant residue.

Water conservation - the principal objective of tillage in these regions - can be achieved by preventing runoff losses and by reducing evaporation. Preventing runoff is usually more effective than reducing the evaporation. In particular, there is less risk of crop failure when losses can be prevented at the beginning of the growing season. The surface storage capacity can be increased even with animal traction, possibly by tied or contour ridging. The main drawback of surface tillage as a way of reducing evaporation losses is that the loosened layer will dry out completely and so this operation is effective only when more than 5 - 10 cm of soil has been moistened.

Soil tillage in summer-rainfall areas causes problems because of the conflicting individual requirements and optimum solutions cannot be achieved because of technical limitations. For example, the need to loosen the surface in order to increase the water infiltration capacity is difficult to combine with the need to prevent decomposition of organic matter by reducing the aeration. A compromise must be found. Crop production in summer-rainfall areas generally causes more problems and requires more effort than in winter rainfall areas.

3.2.3 Literature

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3.3 Soil Tillage In Humid And Semi-humid Tropical Climates

The semi-humid tropics are located around the world in a belt between 6 - 8 deg north and 6 - 8 deg south of the equator. Temperatures are high in these regions and deviations from the annual mean are less than the daily fluctuations. The semi-humid tropics are characterized by a principal and a secondary rainy season. The relative air humidity is high from the beginning of the first to the end of the second rainy period and is often not much lower during the main dry period (see Fig. 15). Rain-forests are the natural vegetation of these regions. These protect the soil from direct solar radiation and water erosion.
In a low-input land-use system (shifting cultivation) the plant cover is cleared and burnt in the dry season. The soil is then worked manually with a hoe. Food crops are planted in scattered plots between the tree-stumps, usually as a mixed crop. The yields show a marked decline after 2 or 3 years, mainly because the organic matter in the soil has almost entirely decomposed. The cycle recommences with the clearance of a new plot in the forest. The abandoned plots require at least 10 to 15 years to recover. High temperatures and large volumes of rainfall cause a very rapid degeneration of the soil. The pH value may be as low as 4 to 5. Soils with a high silt content become latosols. These tropical soils are often very shallow.

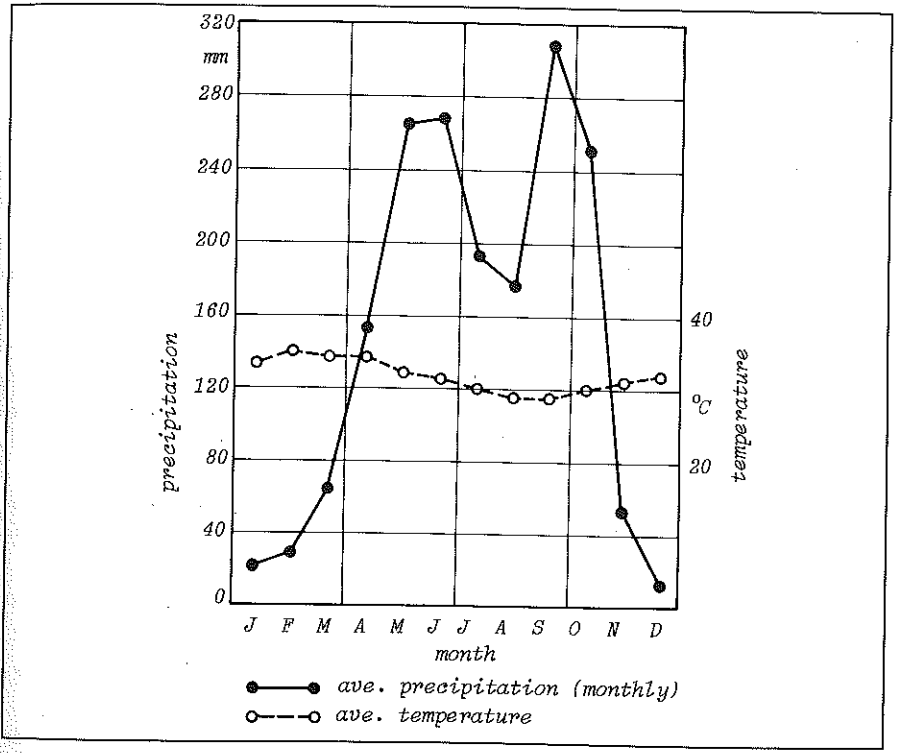

Fig. 15. Humid tropics; Monthly averages of maximum temperature and rainfall in Enugu, Nigeria. - Source: Schreiber.

Arable crops can be successfully and permanently grown on these soils only when the pH value and the organic matter content can be increased and kept at acceptable levels. Many of the fields have to be drained. The latosols - typical soils in these regions - are difficult to cultivate. Since they tend to dry out considerably after being tilled, they are susceptible to erosion and have limited nutrient absorption capacity. So they should be kept under cover as long as possible. Tillage should be reduced to a minimum; "no-tillage" systems may perhaps be intermittently employed.
When sufficient organic matter is available - as is often the case in these regions - the stability of the yields can be improved by an appropriate crop rotation combined with a gradual incorporation of adequatly pulverized organic material.
The climate usually allows crops to be grown throughout the year. This often means that harvesting and tillage operations for the next crop have to be carried out under adverse conditions. The soil will often be too wet; harvesting operations may compact or destroy the soil structure (puddling, creation of ruts).
It is essential to limit the number of operations. In addition to preventing erosion, weed control must be a primary objective of the tillage operations. Minimum-tillage methods which use plant residue as a protective mulch are beneficial as regards the soil structure and erosion control but usually fail because of (perennial) weed infestation.

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4.0 SOIL EROSION