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ASAC 1101 : FUNDAMENTALS OF SOIL SCIENCE (2+1)

Level : B.Sc (Ag), I semester

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Topic

**Puddling and its Effect on Soil
Properties**

Soil Puddling and its Effect on Soil Properties

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What is puddling ?

The term **puddling** was defined by **Buehrer and Rose (1943)** as

“the **destruction** of the **aggregated** condition of the soil by **mechanical manipulation** within a **narrow range of moisture** contents above and below **field capacity (0.3 bars)**, so that soil aggregates lose their identity and the soil is converted into a **structurally more or less homogeneous mass** of ultimate particles.”

After puddling, a soil is called a **puddled soil**, defined as a

“**dense soil with a degraded soil structure**; dominated by massive or **single-grain structure**, resulting from handling the soil when it is in a **wet, plastic condition** so that when it **dries it becomes hard and cloddy**.” (Gregorich et al., 2001).



(a) Primary cultivation with a two disc plough –flooding started when cultivation started



(b) Peg tooth harrow (left), puddling with a peg tooth harrow (right)



(c) Puddling in deeper water (left) and soil levelling (right)

Stages of puddling process

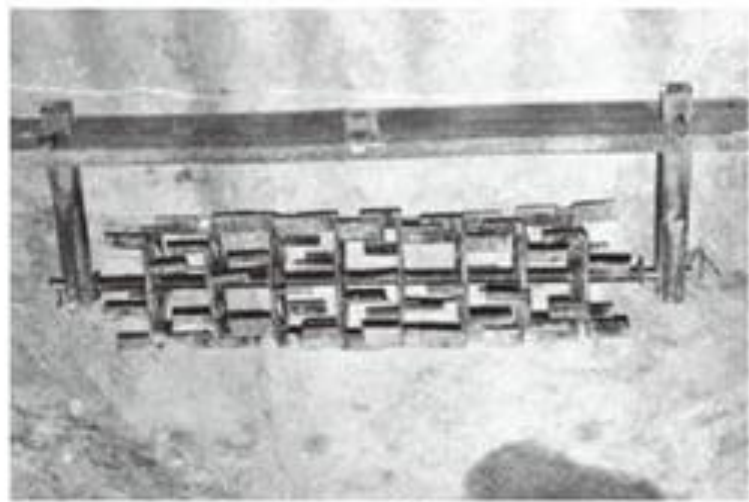


Fig. 1 Implement factory puddler

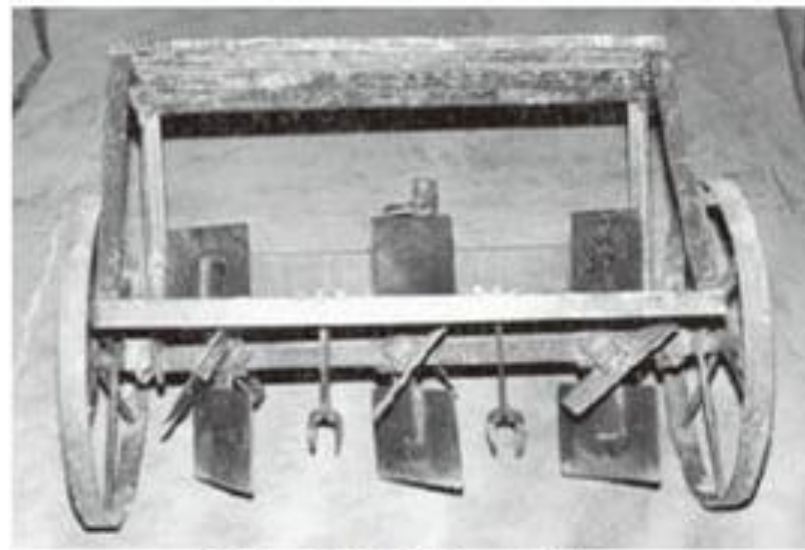


Fig. 2 CAET puddler

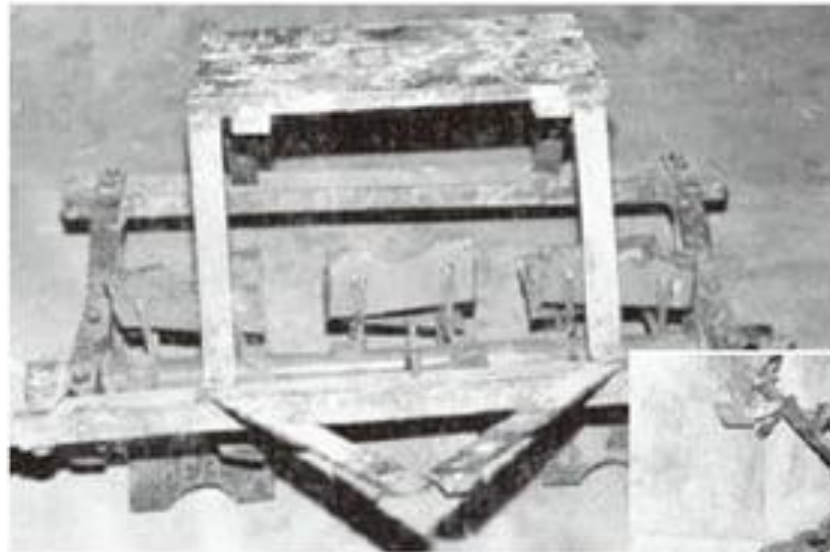


Fig. 3 APAU puddler



Rotary blade puddler



Fig. 4 UP Agro-industry disc harrow cum puddler

Traditional implements for puddling



Advantages of Puddling:

Although puddling, as practiced in much of tropical Asia, involves a great amount of labor, the method has been widely adopted primarily because of its compatibility with other components of production technology and economic conditions, which include:

- Improved weed control by primary and secondary tillage through puddling
- Ease of transplanting.
- Establishment of a reduced soil condition, which improves soil fertility and fertilizer management.
- Reduced draft requirements for primary and secondary tillage.
- Reduced percolation losses resulting in conservation of water from rainfall action and irrigation completed.
- Reliability of monsoon rains by the time puddling operations have been completed (De Datta et al. 1978).

➤ Process of puddling

The process of puddling in rice culture is accomplished by a series of tillage operations beginning at soil moisture contents above saturation (i.e., flooded) and ending at moisture contents closer to field capacity (see Field water cycle).

This process is best understood by considering the changes in soil strength within aggregates and between aggregates.

According to Koenigs (1961), the cohesion within soil aggregates decreases with increasing soil moisture contents. The individual aggregates become soft and may or may not disintegrate depending on their stability. The cohesion between aggregates is very low at low moisture contents but increases rapidly with increasing moisture, peaking at about field capacity, and decreasing sharply as moisture contents approach saturation.

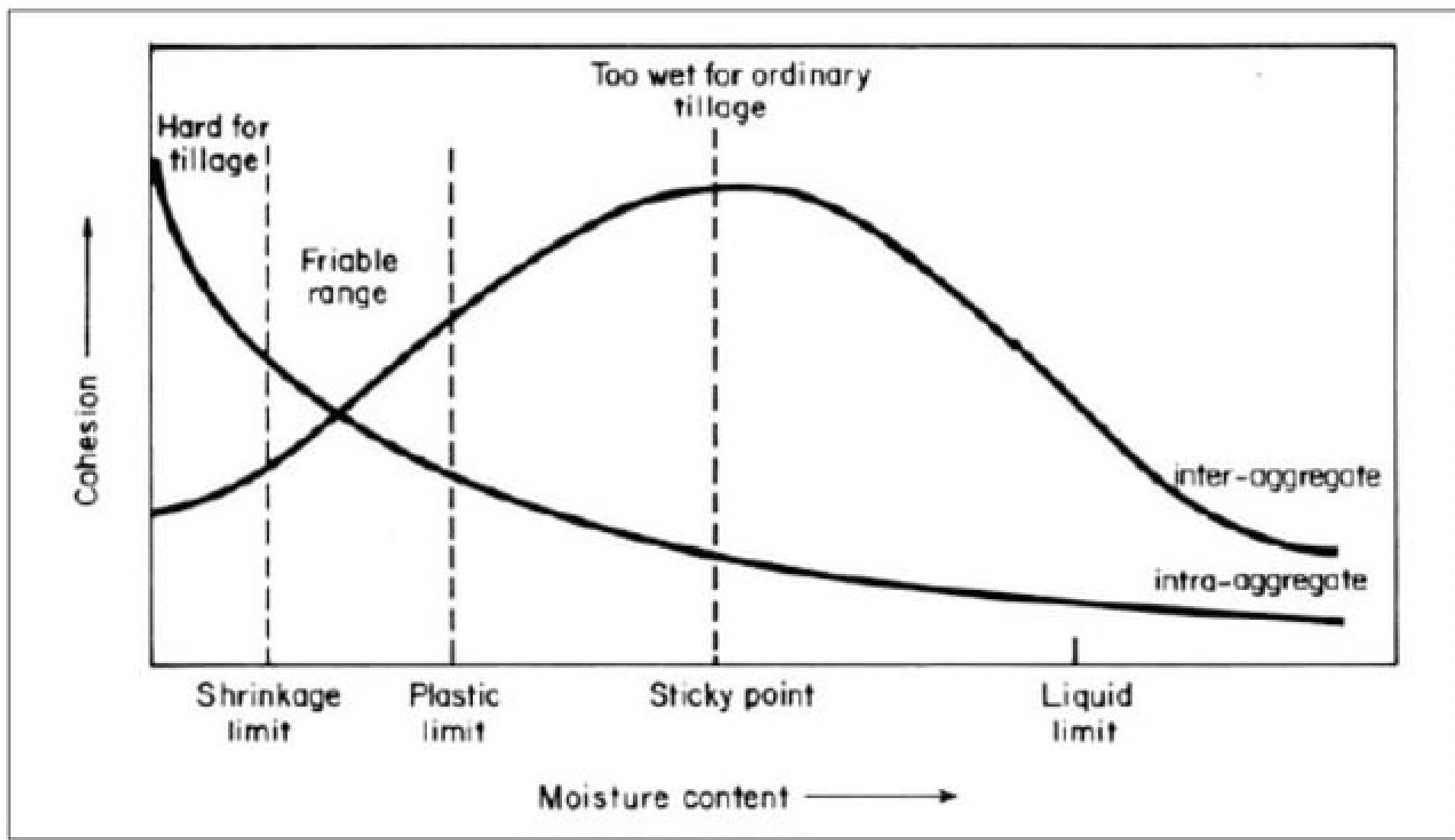
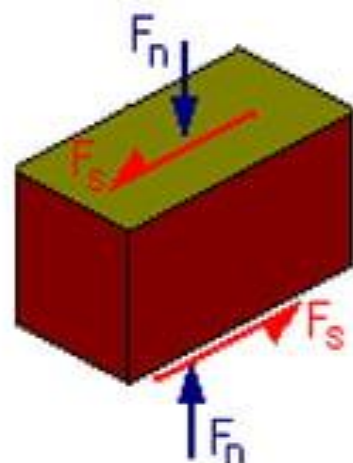


Figure 3.3 Relationship between moisture content and consistency indices to inter- and intra-aggregate cohesion of soils. (From Briones 1979)

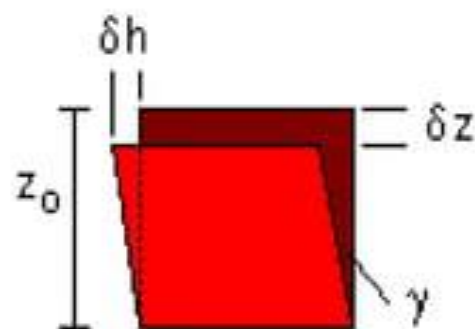
Definition of stress and strain

The reaction of a solid body to a force F or a combination of forces acting upon or within it can be characterized in terms of its relative deformation or strain. The ratio of force to area where it acts is called stress.



area A


normal stress
 $\sigma = F_n / A$
shear stress
 $\tau = F_s / A$



normal strain
 $\epsilon = \delta z / z_0$
shear strain
 $\gamma = \delta h / z_0$

Note that compressive stresses and strains are positive and counter-clockwise shear stresses and strains are positive.

Apparent Specific Volume of Soil.

Change in the apparent specific volume of soil reflects the susceptibility of a soil to puddling. Puddlability is the change in apparent specific volume per unit of work expended. The change in the apparent specific volume of soil is the difference between apparent specific volume after and before puddling (Bodman and Rubin 1948):

$$\Delta ASV = ASV_{ap} - ASV_{bp}$$

where ap = after puddling, bp = before puddling. The data are expressed as cm^3/g .

If the density of water is considered equal to 1 g/cm^3 , which is usual in engineering works

(McCarthy 1977), the equation will be

$$ASV = m + \frac{1}{D_p}$$

where m = mass of water per unit mass of oven-dry soil, or gravimetric moisture content, and D_p = particle density (Bodman and Rubin 1948).

Maximum puddling occurs at moisture contents between

➤ **field capacity and saturation.**

At such moisture contents, the **cohesion within soil aggregates** is **minimum**, so shear planes may easily form.

Moreover, when **aggregates of dry soil are wetted**, **uneven swelling and explosion of trapped air** also helps form **shear planes.**

➤ At **moisture content below saturation**, **cohesion between the aggregates and clods** is **maximum**, and movement of aggregates along each other and along the implement is therefore restricted.

➤ Consequently, the **energy of the puddling implement** is effectively transferred to **shear** and destroy the **aggregates.**

The cohesion between aggregates depends primarily on the number of contact points between aggregates.

The number of contact points is minimal in a dry soil and approaches a maximum at about field capacity because of the increased thickness of water films and the swelling of the aggregates themselves.

At **higher moisture contents**, the thick moisture films act as lubricants and decrease the number of contact points between aggregates. At approximately field capacity the cohesion within the aggregates is very low and the cohesion between the aggregates is maximum.

When force is applied by a plow or a foot, the aggregates are easily destroyed because of the combined effects of high friction and low internal aggregate strength

Soils with high cohesion within aggregates, caused by stabilizing agents such as:

- Fe and Al hydrous oxides, calcium carbonates, and organic matter, need a larger energy input for puddling.
- High clay content favors puddling,
- but kaolinitic clays are more difficult to puddle than montmorillonite clays.
- Similarly, Na-saturated clays puddle more easily than Ca-saturated clays.
- **Andepts** and **Oxisols** are extremely difficult to puddle, and the degree of aggregate breakdown seems lower than in other soils.

Consequences of puddling

(i) Aggregate destruction

The primary consequence of puddling is the **destruction of soil aggregates** (Sharma and De Datta, 1985). A puddled soil consists essentially of a **two-phase or solid-liquid system**. Individual **clay particles** or clusters thereof are **oriented in parallel rows and are surrounded by capillary pores saturated** with water.

(ii) Changes in porosity

Non capillary pores are essentially eliminated in the process of puddling. Bodman and Rubin (1948) found that 91–100% of the volume occupied by such pores was destroyed by puddling a silt loam.

Capillary porosity increases drastically. Because most of these pores are smaller than 0.2 mm in effective radii, water may move through pores as a liquid but can be lost only as vapor.

➤ (iii) Bulk density

Immediately after puddling a saturated soil, the **apparent specific gravity or bulk density** is **less** than that of the original soil because of the larger total pore volume occupied by water. With time, however, the **bulk density of the flooded soils increases** probably because of a **slow settling of the clays.** When **dried**, puddled soils **shrink** dramatically with resultant large **increases in bulk density** (Sanchez, 1968).

➤ **(iv) Increased soil moisture retention**

As a consequence of the **destruction of noncapillary pores**, the **increase in water-saturated capillary pores**, and the **decrease in initial bulk density**, puddled soils **hold more water** than unpuddled soils at a given moisture tension.

The effect is measurable within a range of **0 to 10 bars of soil moisture tension**.

(V) Decreased moisture losses

The changes in porosity and water retention result in sharply reduced soil moisture loss patterns in puddled soils (Sharma and De Datta, 1985).

Puddling decreased **percolation losses** by a **factor of 1000** regardless of soil properties.

➤ Reducing conditions

Due to the absence of air, reduction processes can take place as soon as the soil is puddled (Breazeale and McGeorge, 1937).

Puddled soils remain reduced regardless of whether they are flooded until cracks begin to form. Lack of oxygen in the soil pores inhibits the growth of most crops except rice and other anaerobic species.

Nitrates are lost through denitrification (Aggarwal, 1995).

➤ Organic matter decomposition

Puddling, like any other aggregate disruption process, **temporarily hastens organic matter decomposition** due to increased **accessibility of the substrate** by soil microorganisms. Puddling increases the **mineralization** of soil organic nitrogen during the **first month after puddling** and flooding (Harada et al., 1964), but the **effect disappears at later stages** (Briones, 1966).

➤ Nutrient availability

- Puddling flooded soils does **not directly increase** the availability of nutrients to the rice plant (Sanchez, 1973)
- Small increases in **iron and manganese** availability have been recorded (Naphade and Ghildyal, 1971) but are not large enough to be of practical significance.
- Puddling often indirectly increases the availability of nutrients by **decreasing leaching losses of cations** such as NH_4^+

➤ Effects of puddling on crop growth:

The effects of puddling on crops **other than rice are clearly detrimental** (McGeorge and Breazeale, 1938).

For **rice, puddling is considered advantageous** because it facilitates land leveling, permits the farmers to work the soil regardless of moisture status, reduces initial weed infestations, and, most important, **decreases water and leaching losses.**

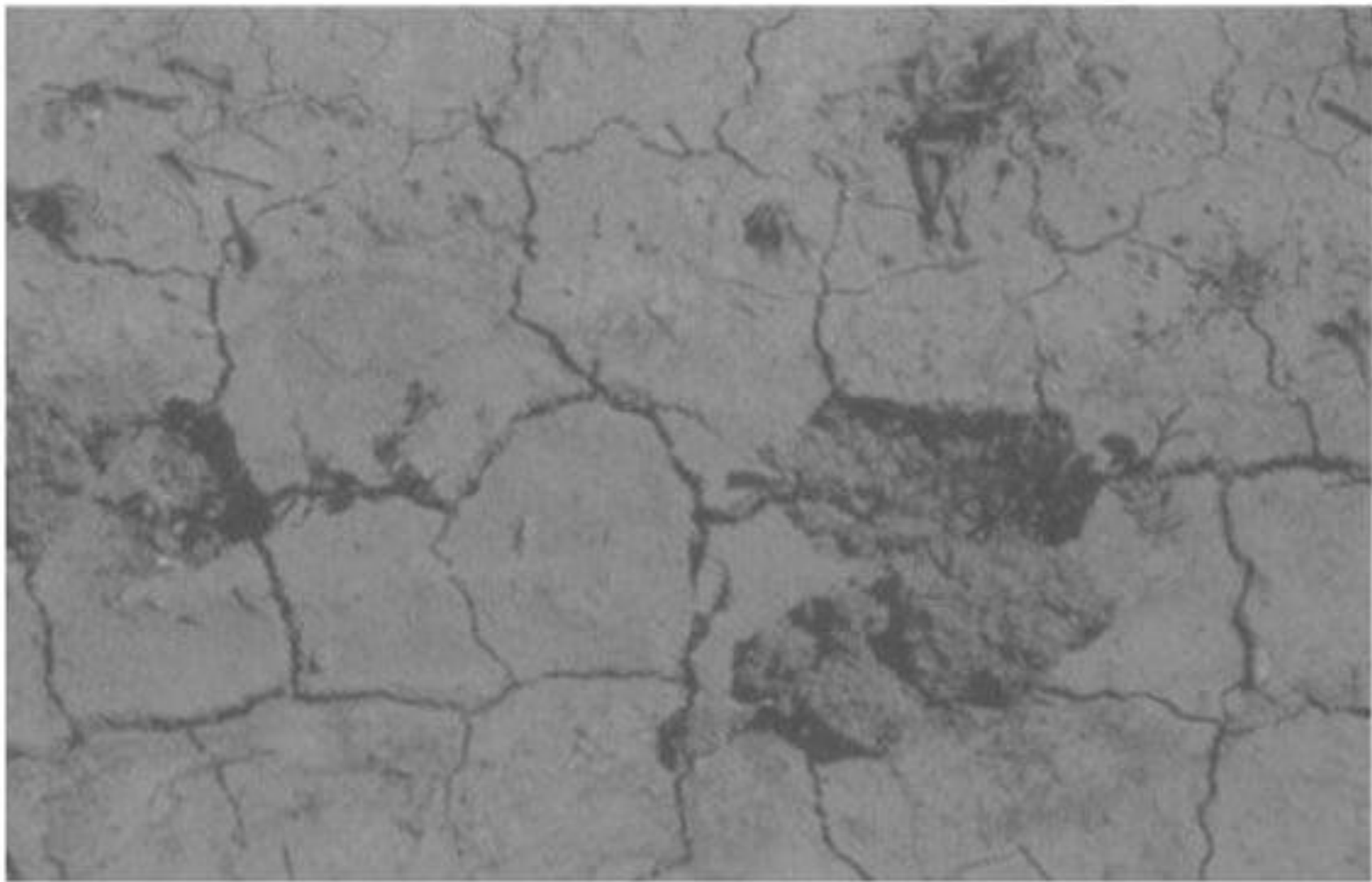
➤ Regeneration of structure

- Puddling is **not an irreversible** process. The original structure can be regenerated through the processes of **alternate wetting and drying or freezing and thawing.**
- The puddled soil must be **dried first**, after which aggregates are reformed by these processes.
- **Tillage at the appropriate moisture content facilitates regeneration of structure.**
- This is accomplished most readily in soils **high in organic matter or iron and aluminum oxides** (Koenigs, 1961).

Briones (1977) concluded that **montmorillonitic clay** soils with **low organic matter** and **iron oxide** contents are more difficult to convert from lowland to dryland use than **kaolinitic clay with higher organic matter and iron oxide contents.** This indicates that **incorporation of crop residues** aids regeneration of soil structure.

Effects of puddling on soil properties (Ghildyal 1978):

1. coarse aggregates are broken down;
2. noncapillary pore space is destroyed;
3. apparent specific volume decreases;
4. water-holding capacity increases;
5. hydraulic conductivity and permeability decreases;
6. evaporation decreases;
7. soil reduction is favored



Drying of the puddle soil leads to formation of cracks, which may have an adverse impact on root growth of rice seedlings.

Dry land Vs Puddled Land

- Puddling and subsequent flooding differentiate lowland rice soils **chemically and pedologically** from other arable soils.
- An important difference between a dryland and a puddled lowland soil is the **presence of the reduced soil layer in the puddled soil system.**
- The puddled layer is divided into several **subhorizons.**
- The formation of relatively impermeable layers, or **plow pans**, is attributed to **physical compaction** (at the same depth) during **puddling, and to eluviation** of clays and **reduced iron and manganese.**
- The **plow pan** is found in **loamy soils** that have grown rice for many years and in well drained Latosols, but is **absent in clayey soils, Vertisols, young alluvial, and calcareous soils** (Moormann and Dudal 1964).

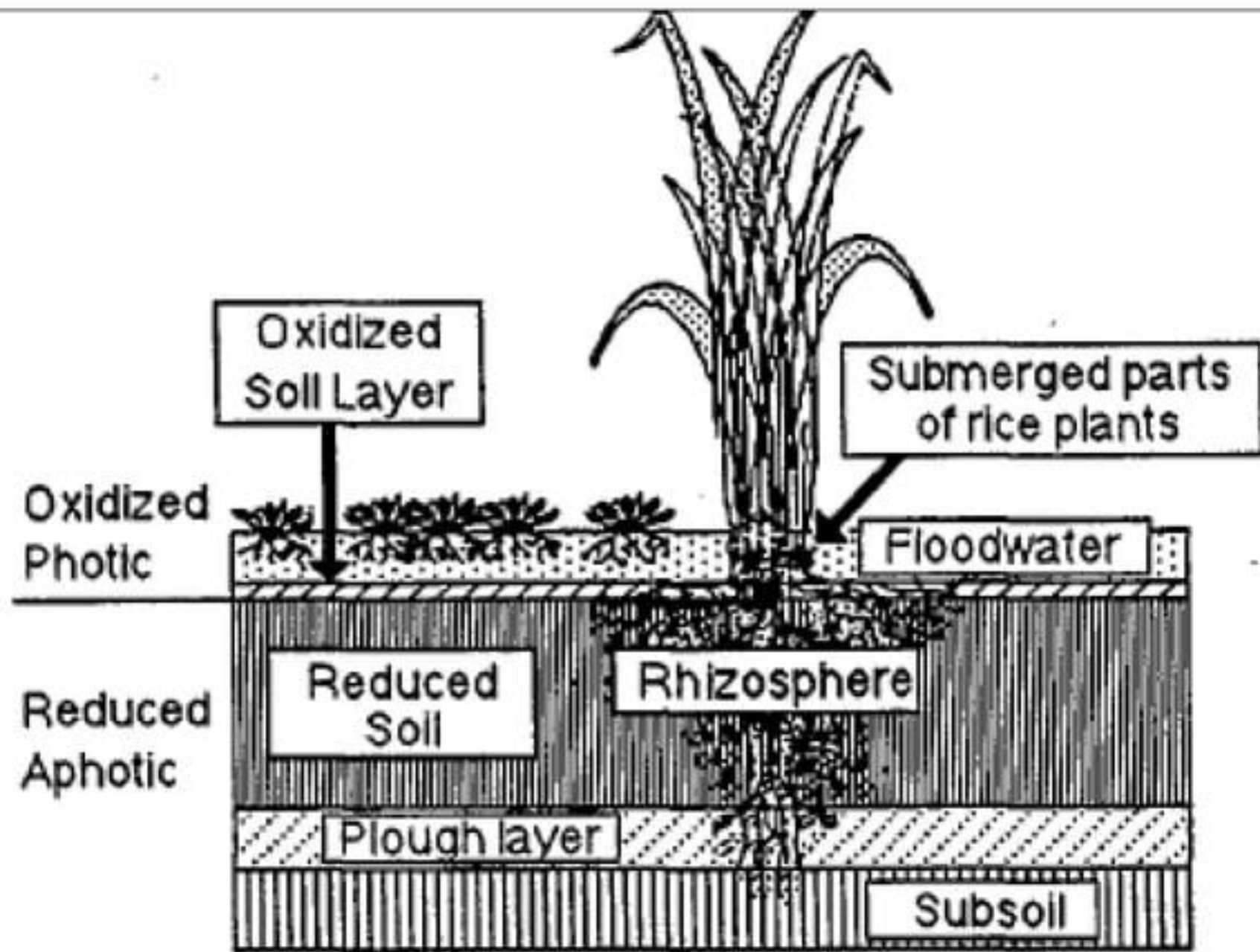
Long-term effect of puddling:

➤ Long-term puddling forms a **hardpan in the subsoil** below the puddled layer. It may take **3 to 200 yr for a hardpan** to form, depending on soil type, climate, hydrology, and puddling frequency (24).

➤ Subsurface hardpans develop from **physical compaction and precipitation of Fe, Mn, and Si.**

➤ **Compact, 5– to 10–cm thick** layers which occur in low land rice soils between **10 and 40 cm depth** and that have **higher (dry) bulk density** and **lower total porosity** and water permeability than the over- and underlying soil horizons were called **plow pans** by Koenigs (in 24) and **traffic pans** by Moormann and van Breemen

- **Chemically cemented pans** are formed in the oxidized subsoil, usually 15 to 20–cm deep, by **precipitation of Fe, Mn, and Si** from upper, reduced soil layers.
- Soils with slowly permeable subsurface horizons, **oxidized subsoils, low pH, high concentrations of easily reducible Fe and Mn**, and easily **decomposable organic matter** favor chemical precipitation.
- Because continuously submerged soils have excessively reduced conditions, **Fe– and Mn–pans form very slowly**.
- Under favorable conditions, Mn– and Fe–pans may develop in 8–40 yr.
- **Ferrolysis** (4) is another long–term effect of puddling that may lower soil productivity.



Macroenvironments of the wetland rice field ecosystem.

Puddling index:

The **puddling** index is the ratio of the volume of settled soil to the total volume of soil sample and is expressed as a percentage.

$$PI = \frac{V_s}{V_t} \times 100 .$$

Where,

PI = puddling index in per cent,

V_s = volume of settled soil and

V_t = total volume of soil sample.

A higher value of puddling index indicates the **better quality of puddling**

THANK YOU