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Puddling and its Impact on Physio-Chemical Characteristics of Soil

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Abstract

Crop management is essential for optimizing agricultural productivity, conserving water resources, and ensuring sustainable farming practices. In context to rice, puddling is an important crop management practice since time immemorial. It provides benefits such as weed control, reduced water percolation, and easier transplanting. However, it disturbs the soil structure and affects the properties of soil, over time, these changes degrade soil fertility and soil health. Slow root development for successive crops like wheat and pulses due to plough pan formation is a serious problem for farmers. However, from production point of view, puddling in rice dominates over unpuddled field. Although it is advantageous in rice production, the negative long-term impact of puddling calls for sustainable alternatives, such as reduced tillage and direct seeding to maintain soil health while ensuring high yields.

1. Introduction

Puddling is a traditional soil preparation technique widely used in rice cultivation, involving the churning of wet soil to create a soft, waterlogged layer that facilitates transplanting and reduces weed competition. Historically, this practice dates back thousands of years, particularly in Asian rice-growing regions, where it became an essential method for ensuring stable rice yields. In ancient times it was carried out by dragging a heavy harrow across the field behind a buffalo, cow or ox. However, in modern days it has been replaced by machines, which is more efficient and time saving. Puddling is crucial in rice cultivation as it enhances water retention, minimizes percolation losses, and provides a suitable environment for young rice seedlings. It is a sustainable practice in rice-rice cropping system, properly managed with good agricultural practices. However, it significantly affects the physico-chemical properties of the soil by breaking down soil aggregates, reducing permeability, and creating a compacted plough pan that hinders root penetration (Kalita et al., 2020). While it temporarily improves nutrient availability and weed control, repeated puddling can lead to soil structure degradation, increased methane emissions, and

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long-term fertility decline. Additionally, puddling alters soil chemistry by disrupting microbial activity, reducing organic matter content. These changes can ultimately impact soil fertility, making it less suitable for crops other than rice. Given these challenges, sustainable alternatives such as conservation tillage and direct seeding are being explored to maintain productivity while preserving soil health. Understanding the impacts of puddling is essential for developing sustainable rice production methods that balance productivity with soil health. In this chapter we will explore a bird eye view on the impacts of puddling on various properties of soil to develop a sound knowledge on rice crop management.

2. Puddling

Puddling is the process of churning and compacting soil with standing water to create a soft, muddy impervious layer below the surface. It involves soil saturation and breaking up aggregates through ploughing and harrowing. It is commonly used in rice cultivation to retain water, provide soft seed bed and suppress weeds.

Steps of Puddling (Reddy and Reddy, 2016)

➢ Initially, the soil is saturated with 5-10 cm of water depending on the soil moisture status, and then the first ploughing is done.

➢ After 3-4 days, 5cm of water is applied and after 2-3 days, second ploughing is done.

➢ Another 5cm of water is given within 3-4 after the second ploughing, then it is followed by third ploughing.

➢ It is done by using wetland plough or puddler and planking is done for land levelling.

➢ If the mud flows freely through fingers with no hard lumps, then puddling is completed.

Figure 1: Tractor drawn puddler

Figure 2: Animal drawn puddler

3. Objectives of Puddling

1. To obtain a soft seed bed for the seedlings to establish themselves faster.

2. Reduced draft requirements for tillage.

3. To minimize leaching losses of N (nutrients) and thereby increase the availability of plant nutrients by achieving a reduced soil condition

3. Suppression of weeds

4. To mix organic matter with the soil.

5. To create an impervious sub soil layer for reducing deep percolation & leaching losses.

6. To facilitate easy transplantation.

Puddling can be done by ploughs, tiller or tractor drawn implements depending upon their availability and soil conditions.

4. Reactions under Water Logged Situations

Soils under lowland/submerged/waterlogged conditions develop fundamental characteristics different from those of soils under upland conditions.

Waterlogged/flooding causes changes in physical, microbiological & chemical properties of soil because of the physical reactions between the soil and water and also because of the biological and chemical processes set in motion as a result of excess water. These changes have a profound bearing on nutrition and fertilization aspects of rice cultivation.

The most important change in the soil as a result of water logging is the conversion of the root zone of the soil form an aerobic environment to an anaerobic or near anaerobic environment where O_2 is limiting. The flooded

or waterlogged soils develops two zones:

1. The upper zone

A thin 1–10 mm thickness, absorbs O_2 from the water and turns brown in colour (oxidized zone) and reacts to N like an unflooded upland soil.

2. The lower zone

The remaining lower portion of the puddle soil turns to a dark or blue green colour as iron compounds in the flooded soils lose their O_2. This soil zone is said to be in reduced state.

Redox Potential (Eh) : It gives an indication of oxidized reduction potential. It is measured in mV (+700 to -700)

- Highly reduced soils -300 to -100
- Reduced 0 to +100
- Moderatly reduced +200 to +350
- Aerated oxidized +350 to +450

5. Effects of Flooding on Soil Properties

Since rice is predominantly grown under wetland conditions, it is important to understand the unique properties of flooded soils for better management of fertilizers for this crop. When a soil is flooded, the following major chemical and electrochemical changes take place. These will have a profound influence on soil nutrient transformations and availability to rice plants.

5.1. Sequential chemical changes that occur during submergence and puddling in rice (Fageria *et al.*, 2011)

1. Depletion of oxygen (O_2) molecules and changing in soil oxidation & reduction systems.

2. Chemical reduction of soil, characterization of the oxidized & reduced zones and decrease in redox potential.

3. Increase in pH of acid soils and a decrease in pH of sodic & calcareous soils.

4. Reduction of ferric (Fe^{+3}) to Ferrous (Fe^{+2}) and Mn^{+4} to Mn^{+2}

5. Reduction of nitrate (NO_3) and nitrogen dioxide (NO_2) to N_2 and (nitrous oxide) N_2O

6. Reduction of sulfate (SO_4^{-2}) to sulfide (S^{-2}) i.e. extremely reduced conditions.

7. Increase in the supply of availability of nitrogen (N)

8. Increase in the availability of phosphorus (P), silicon (Si) & molybdenum (Mo)

9. Decrease in the concentration of water soluble Zinc (Zn) & Copper (Cu)

10. Generation of carbon dioxide (CO_2), methane (CH_4) & toxic reduction products such as organic acids and hydrogen sulfide (H_2S).

5.2. Physical changes

1. Destroys the structural aggregates in the soil

2. The diffusion/exchange of air between the atmosphere and the puddle soils is impeded

3. Reduced & oxidized zones develops distinctly

4. Apparent specific volume of soil decreases

5. Non capillary pore space is destroyed

6. Decreases hydraulic conductivity

7. Bulk density of soil increases

8. Alters the distribution of sand, silt and clay by mixing different horizons of soil

9. Plough pan creation resisting roots of succeeding crops

5.3. Biological changes

1. The rate of decomposition of organic matter is considerably reduced in wet land soils.

2. The organic matter N is changed to ammonia (NH_4) form (stable under water logged conditions) and denitrification losses will take place.

6. Disadvantages of Puddling

- Excessive water use
- Low traffic ability
- Difficulty of regenerating soil structure for the dryland
- Hindrance in regenerating soil structure
- High water requirement , as about 100-300 mm of water is required to saturate the soil for puddling
- Hard pan formation, delaying subsequent crop growth
- Dispersion of fine clay particles
- Forms large clods in finer textured soils
- High energy consumption due to repeated churning of soil
- Promotes greenhouse gas emission by creating anaerobic condition in the soil

7. Advantages of Puddling

Despite its disadvantages, puddling is widely practiced in rice cultivation because it provides several agronomic and

economic benefits. It helps in weed control by creating anaerobic conditions that suppress weed growth, reducing the need for herbicides or manual weeding. Puddling also improves water retention by reducing percolation losses, ensuring that rice plants have a consistent water supply, which is crucial for their growth. Additionally, it facilitates easy transplanting of rice seedlings by creating a soft and level surface, leading to uniform crop establishment and better yield. The process also helps in nutrient retention, as the compacted layer minimizes nutrient leaching, making fertilizers more effective. While puddling may have drawbacks like soil structure degradation and higher water usage, its advantages in ensuring successful rice production, particularly in traditional flooded systems, often outweigh these concerns in regions where rice is a staple crop. However, efforts are being made to develop alternative methods, such as conservation tillage and direct seeding, to reduce the negative impacts while maintaining productivity.

8. Conclusion

Puddling significantly alters the physico-chemical properties of soil by breaking down soil aggregates, reducing permeability, and creating a compacted plough pan that affects root penetration and aeration. It enhances water retention but also increases greenhouse gas emissions. While it temporarily improves conditions for rice cultivation, repeated puddling can degrade soil structure, lower organic matter content, and disrupt microbial activity, impacting long-term soil health. Sustainable alternatives like reduced tillage and direct seeding are being explored to balance productivity with soil conservation.

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