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Role of mulching in
climate-smart regenerative agriculture

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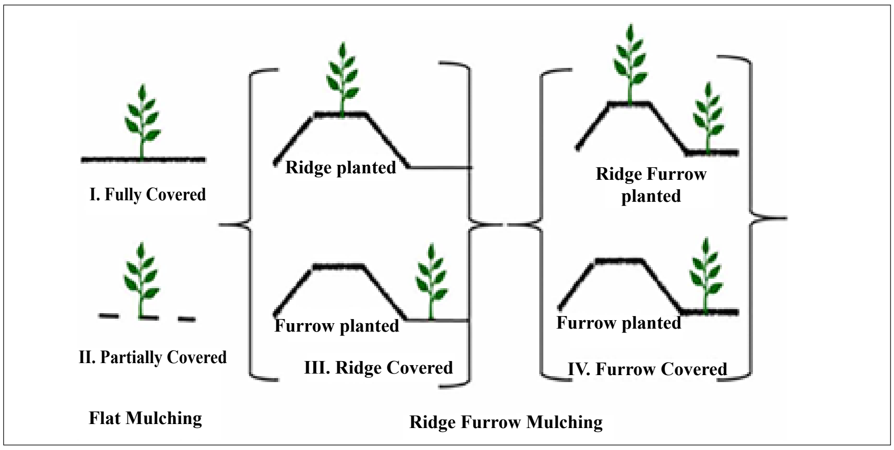
Climate change and 'yield decline' are the two greatest challenges for food and nutrition security. Curtailing greenhouse gas emissions, and improving the capacity to adapt and grow crops are needed to face the challenges of climate change. Similarly, to face the challenge of 'yield decline', organic plant nutrient supply and pest management are needed in addition to reduced tillage. Both the challenges can be solved by 'climate smart regenerative agriculture' (CSRA) practices such as regular addition of organic matter, covering the soil surface with vegetation wastes, avoiding intensive tillage, and least use of chemical fertilizers and pesticides. Enriching the soil organic matter pool and beneficial organisms is the key to reverse the challenges. Mulching is an important practice to fulfill these objectives with adaptive, mitigative and regenerative roles. Adaptive roles include managing high evaporation loss and irrigation demand, and moderation of soil and air temperature in microclimate. Mitigative roles include carbon sequestration and halting carbon loss from soil. Regenerative roles include enriching the carbon, nutrients, and microbes in soil, and improving the soil structure. Ultimately, crop yield is increased due to stress avoidance and favourable soil health.

Keywords: Adaptation, Mitigation, Natural farming, Organic farming, Regeneration

WITH the rise in population, there is an increased demand of food directly for human consumption and indirectly for farm animals to meet the increased demand of meat, milk and eggs. To meet such demands, there has been an expansion in cultivated area, and crop intensification in space and time. This has resulted in an unsustainable use of land, water, fertilizers, pesticides and diesel, resulting estimated fertile soil loss of 24 billion tonnes per year globally. (UNCCD 2017). Agriculture is the second-largest sector accounting 19.9% share in CO_2-eq emission after the energy sector (68.1% share) (FAO 2022). The generated pollutants have direct and indirect adverse effects on animal and aquatic habitats, predator-prey relationships, and a fall in biodiversity. Among the crops, rice is important in terms of the climate crisis. Rice contributes 2.6 times more CO_2-eq emission/kg grain than other cereals. About 65 thousand tonnes of CH_4, 1.7 thousand tonnes of N_2O and 1897 thousand tonnes of CO_2-eq emissions were generated from rice residue burning in India during 2019. To reverse the trend, there is an urgent need to curtail the GHG emissions and develop the adaptation measures.

'Climate-smart agriculture is an integrated approach to manage landscapes-cropland, livestock, forests and fisheries- that address the interlinked challenges of food security and climate change' (World Bank 2024, https://www.worldbank.org/en/topic/climate-smart-agriculture). The smart practices and technologies enhance resilience, reduce GHG emissions and boost productivity. Resilient practices reduce the vulnerability of crops to climate driven stress and improve the capacity to adapt and grow. Emissions can be reduced by minimizing tillage and agrochemical use, and by adopting water and carbon efficient practices. Regenerative agriculture focuses on restoring the soil health, which has been degraded by the over use of heavy machinery, fertilizers, pesticides and irrigation. It considers agroecological and socio-economic specific practices such as conservation and sustainable management of resources, precision farming, non-chemical pest management, and use of resilient cultivars and organic manure. Mulching is an important practice to fulfill these objectives.

The English word 'mulch' is derived from German word "molsch", which means soft or beginning to decay. Mulching is the practice of covering soil with dry or semi-dry plant materials such as leaves, twigs, husks, weeds, crop residues, stubbles, saw dust, and by-products from horticultural and forestry production and processing, for the benefit of soil and crops. Mulch mainly means wastes of plant origin. In anchored mulching, the straw and stubble of harvested crops are still anchored to the ground and the next crop grows along with. Polythene mulches of different colours and thickness are also used. However, its use is not desired considering the microplastic pollution. Also, the benefit of carbon and nutrient addition, and improved soil health is not possible, and it is prohibited in organic and natural farming.



Schematic diagram of mulching methods (___line indicates mulched surface) Shaikha *et al*. 2023

Suitable mulching materials

Ideally, mulch should be soft, light in weight, voluminous and decomposable. Locally available plant materials, preferably generated from or near the farm are ideal for mulching. The mulching materials are broadly classified as organic, inorganic and special materials. The organic materials include crop residues, weeds, wood dust, bark, geo-textile materials, husks, cover crops, newspaper, kraft paper, cow dung, and manure. Inorganic materials include plastic films and sprayable polymer film. The special materials include stones and gravel. Organic materials decompose at varying rates due to variation in C:N ratio and the content of water, nitrogen and biochemicals. Materials such as *Sesbania*, sunhemp are useful as nutrient sources, but protect the soil for a short time. On the other hand, straw and sawdust decomposes slowly (high C: N), and therefore, cover the soil for a longer period. Nitrogen-rich manures can speed up mulch decomposition, while slow-decomposing mulch is ideal for preventing soil erosion.

Mulching methods

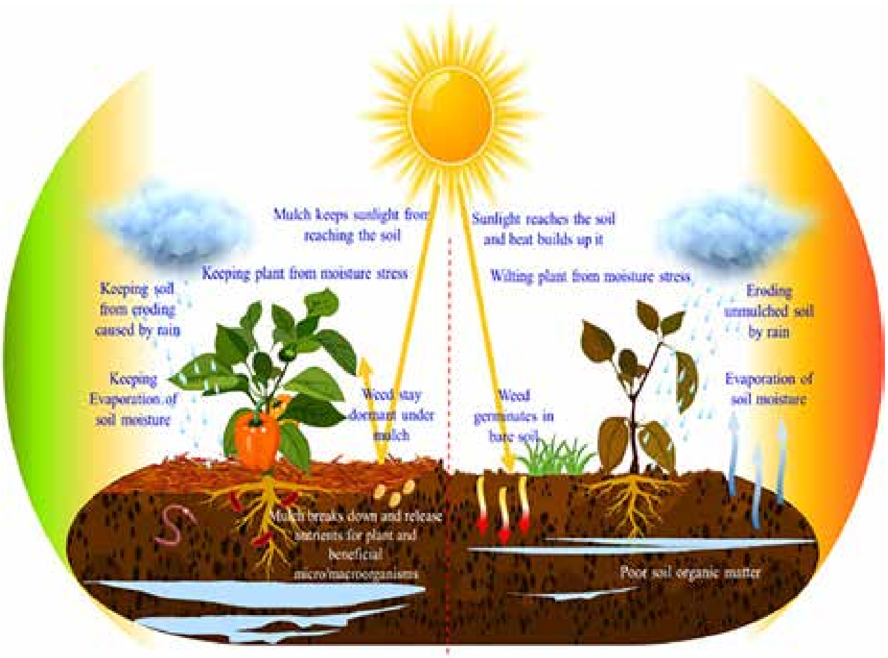
Flat mulching involves covering the materials on flat surface. Ridge mulching, widely used in China's Loess Plateau, involves covering ridges with plastic film to channelize rainwater into furrows, reducing runoff and enhancing water use efficiency. Ridge-furrow mulching covers both ridges and furrows with plastic film or a combination of organic and plastic layers. Crops are planted on the ridge, in the furrow, or both. This method is more effective than flat mulching in harvesting rainwater and reducing soil evaporation.

Mulching as a key practice in CSRA

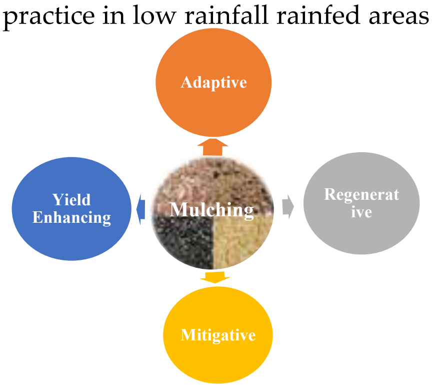
Mulch is a viable option to reverse the environmental degradation by playing adaptive, mitigative, regenerative, and yield enhancing role in CSRA.

Adaptive role

Reducing high evaporation loss and irrigation demand: The primary objective of mulching is to reduce the evaporation loss, and thereby conserve soil moisture for use by plants as 'green water'. It is in practice in low rainfall rainfed areas



Role of mulching for the benefit of soil and crops (Riseh 2024)



Central role of mulching in CSRA

during *kharif* and in high rainfall areas during *rabi*. Rise in temperature and evaporative demand due to climate change necessitates wide use of mulching. Mulching at optimum thickness ranging from 5–15 cm effectively manages the weeds and, there by controls the wasteful loss of 'green water'. Short to medium duration dry spells can be managed with mulching due to the conserved moisture. Also, moisture extraction from a greater soil volume is possible due to the prolific root system in a mulched field. It is reported that the soil moisture content is elevated by 5.8%, 9.0% and 11.1% with the mulching thickness of 2 cm, 4 cm and 6 cm, respectively, as compared to no mulching.

Mulching when integrated with surface drip irrigation or sprinkler irrigation for close spaced row crops saves water by checking evaporation loss. For small plots, in absence of sprinkler, spraying water with power sprayer or knapsack sprayers, especially in the evening, is useful in mulched plots under drought situation. A mulched field can be broadcasted with water soluble fertilizer and then irrigated using sprinkler for placing the nutrient in root zone along with the percolating water. Such application in the late afternoon or evening is useful to reduce the loss of both the inputs. Also, sprinkler irrigation on mulch in the afternoon favours dew harvest in night, especially in cool humid areas.

Temperature moderation: Extreme weather events such as heat waves and cold waves occur in climate change era. The adverse effects of high temperature on summer crops and low temperature in winter crops is expected. Mulching is useful in warming the soil in winter season and cooling in hot summer by about 1 to 2 °C. It also moderates the microclimate around the plants. A very fast rate of sprouting of potato tuber and subsequent plant growth was observed with the mulching in winter season. This was due to warming of soil and the microenvironment for potato crop as compared to the non-mulched area when the minimum air temperature fell below15 °C.

Table 1. Effect of mulch on emergence, growth, yield and economics of potato plants (Pooled data of 2010–11 and 2011–12)

Treatment	Plant height (cm)	Leaf area index (60 d)	Tuber yield (t/ha)	Net return (₹ x 10^3/ha)	B: C	Production Efficiency (kg/ha/day)	Economic Efficiency (₹/ha/day)
No mulch	50.7	2.18	9.74	20.3	1.35	97.8	782
Mulch	54.9	2.80	12.10	38.2	1.65	123.3	987
CD (*P*=.05)	0.720	0.083	0.23	-	-	-	-

Satapathy *et al.* (2016)

Paddy straw mulching in potato

Similarly, for the geographic regions with high temperature in summer (air temperature exceeding 30 °C), plant growth is adversely affected. Healthy flowers, and low fruit and flower drop is observed in mulched pointed gourd in hot summer indicating the benefits of mulching against heat waves. The fruit quality was also better as the fruits did not touch the soil.

Weed management: Rise in temperature and frequent dry spells under the climate change is likely to enhance the problematic grassy weeds. On the other hand, management of weeds is a great problem due to labour scarcity, decreased efficiency of workers, and increased awareness regarding the adverse effects of herbicides. Use of herbicides in organic and natural farming is forbidden. It is also not desired due to adverse effects on earthworms and beneficial microbes. With a mulch layer of sufficient thickness (5–15 cm), weed germination and growth is suppressed due to cut-off of sunlight, physical obstruction and allelopathic effects. About 10 t/ha of residue as mulch significantly reduced weed emergence and biomass as compared to no mulch.

Mitigative role: Soil organic carbon content is increased with the decomposition of organic mulch and enhanced biological activity. Enhanced proliferation and activity of roots in mulched soils adds organic matter. Rather, the loss of organic carbon due to oxidation during the tillage and hoeing can be avoided in mulched fields due to biotillage by earthworms and root

Paddy straw mulching in pointed gourd

activity. The soil organic carbon increased by 2.3%, 2.4% and 3.0% for a mulch thickness of 2 cm, 4 cm and 6 cm, respectively. In Indonesia's hilly humid regions, *Paspalum conjugatum* improved soil physical properties, organic carbon, aggregate stability, porosity, and moisture availability.

Regenerative role: Organic mulch enhance the organic matter and plant nutrient content in soil. Conservation of soil moisture, addition of organic matter and plant nutrients, and shading enhances the activity of soil organisms such as earthworms and microbes due to supply of feed and creation of a favourable environment. This helps in fast decomposition of organic matter and continuous release of nutrients. Potassium content in mulch is released very fast when moistened. In a meta-analysis, 4.9%, 17.69%, and 3.98% higher nitrogen use efficiency values for rice, maize, and wheat, was reported respectively, under mulching compared to no-mulching. Sufficient activity of plant roots, macro- and micro-organisms create a stable crumb structure with enough macro- and micro-pores. These pores serve as conduits of rainwater into the soil and reduce the runoff loss. Mulching avoids formation of surface crusts and thereby don't obstruct the emergence of seedlings and water infiltration into the soil. Also, the kinetic energy of rain drops is dissipated on mulch and does't detach the soil particles. Wind erosion is also reduced.

Yield enhancing role : Yield enhancement occurs due to avoidance of moisture stress during dry spells and temperature moderation. Yield benefits due to mulching is especially observed in crops such as potato, ginger and turmeric whose economic part grows underground. Potato yield was increased from 9.74 t/ha to 12.1 t/ha due to mulching (Table 1). This resulted in higher net return, B:C, and production efficiency. Long-term use mulch is useful in regenerating soil and checking the 'yield decline'. Early release of potassium from mulch is especially beneficial in reducing the late blight incidence and severity in potato. In saline soils, organic mulch increases the solute potential and improves plant growth and yield. Moreover, during the leaching, the efficiency of straw mulching on desalinization is superior to just leaching. Reduction of diseases and weeds helps in checking yield loss.

Problems and prospects in adoption of mulching

Availability of enough vegetation wastes at the time of need is the biggest constraint. Also, the practice is labour intensive. Sometimes, rats, ants, termites, slugs and snails multiply fast and create problem. Stem borers may survive in the mulched stalks of cotton, maize, rice and sugar cane. Similarly, plant material infected with viral or fungal diseases should be avoided. Excessive organic mulch can lead to moisture build-up, anaerobic conditions, and root rot. Straw mulches, with their high C:N can immobilise N.

The prospect of organic mulching outweighs the problems considering the yield advantage, soil regeneration and the adaptation and mitigation role in climate change scenario. Labour need for collection and spreading of mulch is compensated by avoidance of weeding, hoeing and earthing up, and reduced irrigation frequency. Mulching is especially desired in organic farming and natural farming, and such produce fetches high price in market. The Fukuoka system of mulching rice fields is an inspirational example. In this success story, white clover is sown with rice, one month before harvesting. Shortly thereafter, winter rye is sown. After threshing, the rice straw is brought back to the field as mulch. Both the rye and white clover grow through the mulch. If the rice straw decomposes too slowly, chicken manure is sprinkled over the mulch. This cropping system does not require tillage, but achieves satisfying yields. Such location specific mulch based farming is needed to reverse the climate change and yield decline.

SUMMARY

In CSRA, mulching conserves soil moisture, reduces evaporation, suppresses weeds, influences soil microorganisms, and improves soil structure and temperature. Mulch alters the soil's hydrothermal regime, and microbial activity. By modifying the microclimate and reducing evaporation, mulching significantly contributes to water conservation and carbon sequestration. The practice improves soil health, use efficiency of inputs and crop yield. Benefits from mulching outweighs constraints and proves as a key practice for CSRA.

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