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Regenerative Agriculture: Principles And Practices

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***Abstract**:*
Regenerative agriculture principles and practices are imperative in the world's transition to sustainability, as agriculture is one of the chief contributors to climate change. Prior research has identified multifold ecological and socioeconomic benefits of regenerative agricultural systems, but does not focus on or attempt to systematically review practices in specific geographical and economic contexts such as that of Tamil Nadu. This paper elucidates and evaluates selected practices of crop cultivation in regenerative agriculture, based on interviews with practitioners of RA and the case study of a farm in the Auroville experimental township, Tamil Nadu to provide insights into on-the-ground practices. Policies to promote RA are recommended based on the findings and the identification of policy gaps.

***Keywords:** Regenerative Agricultural Practices, Sustainability, Organic Farming, Conservation, Sustainable Farming Systems.*

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I. Introduction: The Case for Regenerative Agriculture

In the world's transition to a circular, sustainable economy, integrating regenerative principles is imperative when agriculture remains among the foremost emitters of greenhouse gasses, contributing more than a quarter of emissions (Poore & Nemecek, 2018), a primary driver of land degradation, and the most water-consuming activity in India (*India: Issues and Priorities for Agriculture*, 2023). Though there is no uniform definition, Schreefel et al. propose a definition of Regenerative agriculture as "an approach to farming that uses soil conservation as the entry point to regenerate and contribute to multiple provisioning, regulating and supporting services, with the objective that this will enhance not only the environmental, but also the social and economic dimensions of sustainable food production." (Schreefel et al., 2020). In this paper, *regenerative agriculture* is used in a similar capacity, as an umbrella term to simultaneously refer to the broad array of sustainable agricultural systems and practices as well as their fundamental principles. The focus of this paper is an elucidation and evaluation of selected crop cultivation methods of regenerative agriculture using interviews with practitioners of regenerative agricultural practices (RAPs) and the case study of a farm in Auroville to provide insights into the reality and ideals of the day-to-day practice.

Although the literature is devoid of multidimensional long-term evaluations of sustainable agricultural methods with respect to the economic, environmental, and social facets of sustainability and agroecological-zones (Pradhan et al., 2021), there is evidence that regenerative agriculture has considerable environmental and potential economic benefits. Large-scale implementation could drastically reduce overall carbon emissions. No-till farming, for example, is an RAP which introduces carbon back into the soil by pressing down crop residues when seeding. Studies suggest that carbon equivalent to almost a third of current anthropogenic CO2 emissions could be sequestered by a global conversion of croplands to no-till systems. No-till farming could reduce erosion to levels close to soil production rates, whereas erosion from conventional agriculture far exceeds production rates as well as geological erosion rates, jeopardizing world food security. Organic farming methods are also proven to preserve and improve soil fertility (R Montgomery, 2007) and RAPs have overall benefits for soil nutrition. Practices like crop rotation and rotational grazing allow soil nutrients to recover before grazing, which enhances nutrient load and cycling. Studies show that regenerative management of ruminant livestock in mixed-crop and grazing agroecosystems can enhance soil nutrient cycling by promoting residual crop biomass decomposition and the regeneration of nitrogen-fixing plant species (Teague et al., 2016). RAPs such as polycultures, cover cropping, crop rotation, mixed cropping, and no-tillage increase farm biodiversity while reducing pest population densities. Organic inputs further nourish the activity of soil microbial communities (Lal, 2004).

The benefits to soil health and the agroecology of the system thus have long-term advantages that result in heightened economic profitability when compared to conventional farms. A feature of regenerative farming for stakeholders to consider is that the yield tends to be low for the initial years, but a level may eventually be attained to rival the yield of conventional producers. The multidimensionality of the benefits of regenerative agriculture, if not the extent, make a strong case for scaling it up. This scaling up holds enormous potential to meet growing population demands on food and grain production.

Benchmarks For Regenerative Farms

There remains ongoing debate about which agricultural systems qualify as sustainable (Pretty, 2007). A framework for regenerative agriculture requires certain benchmarks to specify when a farm is 'regenerative,' if not to pinpoint and maintain the integrity of a definition of a regenerative system. These must be both process and outcome-based, striking a balance between outcome-oriented conventional practices and process-conscious sustainability. Below, the outcomes are listed with elaborations in terms of the processes; these metrics are broad and show overlap with those that might be posed for a conventional farm.

Yield: Existing research critically lacks long-term (more than three years) evaluations of the yield and economic benefits of sustainable agriculture systems, but a general pattern of relatively lower initial yield along with a sustained long-term increase to sustainably match conventional production levels is observed according to all interviewed sources.

In a study analyzing 286 case studies across the eight categories of FAO farming systems in 57 countries, the mean relative yield increase was 79% for 360 reliable comparisons[1]. In all cases except for rice and cotton, a yield increase was reported. For cases involving pesticide usage, 77% of the cases decreased pesticide usage by 71%, concurring with a 42% yield increase (Pretty et al., 2005).

Income: In Auroville, the crops are sold locally with the Pondicherry market a back-up, which is flooded with inorganic, low-price vegetables. The niche of Auroville producers here is in the organic produce market, which is otherwise thought to be exclusive to elite consumers. Auroville producers make organics available at the price of inorganics by driving down costs and increasing abundance on the farms.[2]

The diversification in RAPs that is the pillar of dietary and ecosystem health also reduces economic dependence on one livelihood and promotes income stability and resilience by spreading harvests throughout the year. Livestock cultivation aids in this diversity and increases farm efficiency, considering the potential of manure recycling and similar practices. In fact, separated crop and livestock specialized farms may be counterproductive (Wilkins, 2007).

The sustained increase in yield after the outset is what generates *revenue*, and thus any revenue benchmark is long-term; regenerative farms must reach a point where they can produce output that can compete with conventional farms. Cost-wise, a sustainable farmer income is obtained by focusing on minimizing initial investment by eliminating/minimizing high-cost inputs such as fertilizers and pesticides.

Resource Management: The consumption of exhaustible resources on the farm, from fossil fuels to water, is to be minimized. The optimization of resource consumption is the broad aim of RAPs.

Water: The integration of practices such as rainwater harvesting, precise micro-irrigation, and improvement of soil water-holding capacity to reduce water consumption and irrigation sizeably, as well as mulching which reduce evaporation loss and water requirement, are essential to sustainable systems. Pretty et al. (2005) show that the integration of sustainable agricultural practices involved a consistent increase in water productivity for every major crop type, from 15.5% for rice to 256.6% for fruits and vegetables.

Energy and emissions: Minimization of methane and other emissions from fertilizer usage, renewable energy production/usage, and optimization of energy on the farm are all critical benchmarks. Negative GHG emissions may also be an objective so significant sequestration of carbon and conservation of carbon in soil is one more parameter. The study above quantifies the total carbon sequestered per hectare in the land under sustainable agriculture as 0.35 t C ha^{-1} y^{-1}.

Soil health: The implementation of agronomic practices such as mulching, organic manuring, vermicomposting and cover cropping as well as the minimization of conventional fertilizer usage in favor of natural fertilizers and concoctions to conserve soil health.

Nutrient Management: Soil biodiversity should be managed, for example by using biofertilizers containing organisms such as Rhizobium, Azotobacter, and Azospirillum to enhance nitrogen fixation, soil nutrient availability, and pest protection.

Prevention of Degradation: It is difficult to divorce soil nourishment and protection, but in order to contrast with conventional agricultural practices which inflict long-term degradation using synthetic fertilizers, no-tilling/conservation tillage and other practices to improve soil structure and safeguard against erosion are indispensable characteristics.

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[1]The eight categories are: smallholder irrigated, wetland rice, smallholder rainfed humid, smallholder rainfed highland, smallholder rainfed dry/cold, dualistic mixed, coastal artisanal, urban-based, and kitchen garden.

[2] The strategy is apparently to cultivate crops that are in off-season, not in-season; the seeds must be trained to suit the environment.

II. Biodiversity and ecosystems:

Soil biodiversity: Intercropping and crop covering can achieve this objective. See *nutrient management.*

Pest, weed and disease management: Minimization of traditional plowing in favor of contour plowing, ridging, and other conservation techniques as methods to eliminate weeds and crop residue. Integration of practices like crop rotation inhibit certain types of pest accumulation in the soil. The selection of disease and pest resistant varieties is crucial in regenerative farming systems (National Centre for Organic and Natural Farming, n.d.)**.**

Human Health: A diversity of food sources, lower residue burning, and minimized pesticide/chemical exposure ameliorate public health. In general, RAPs do not employ synthetic inputs and exposure to pesticides is associated with the development of cancers, with a particular risk for children (Bassil, 2007).

Methodology

This paper uses an interview-based approach to consolidating information on the systematic practice and results of regenerative agriculture as it is practiced by Tamil farmers. Given the geographical context-specific nature of the subject, interviews with on-the-ground stakeholders was identified as a more insightful method of data collection than sourcing data from academic literature. Umaramanan, farmer, project leader, head of training modules, and regenerative farming consultant at AuroOrchard was consulted on the details of his regenerative farm for this paper, alongside a series of interviews with representatives of farmer producer organizations and agricultural companies. A business graduate, Ramanan has attended various in-house training sessions in regenerative farming by experts and has been trained in animal husbandry and horticulture by the Tamil Nadu Agriculture Department. Having completed courses in permaculture and ecovillage design, he has 11 years of experience at AuroOrchard with a focus on the management and organization of vegetable cultivation, where he also offers training in organic farming. He reports an appreciably higher profit margin despite a ballpark of 25 bags per acre yielded for every 30 or so bags per acre that a conventional farmer reaps thanks to significantly lower input costs. Although this is a rough estimate and the actual yield varies according to the crop, it agrees with regenerative principles that the absolute yield is less important than cost-efficiency. Reduction in input costs, premium pricing, and diversified revenue sources all result in a net income increase for the farmer as compared to conventional methods.

The interviewed sources from the 2023 AgriBusiness Expo in Chennai gave their informed consent to the interviews and requested not to be identified. The interviewed parties generally included Farmer Producer Organizations (FPOs), agriculture-related departments such as that of Tamil Nadu Agriculture University, representatives of the Agricultural and Processed Food Products Export Development Authority (APEDA), agricultural entrepreneurs and cultivators, private produce companies including cultivators and retailers of organics, and exporters of agricultural products. These sources provided insights on farmer perceptions of regenerative principles and on-ground practices. The oral interviews were ideal to curtail language barriers, but context-specificity may have compromised objectivity in the responses. The sources were not representative in the range of stakeholders or comprehensive in the discussion of RAPs, but this is not necessary as this paper does not aim for a comprehensive definition and evaluation. Interviewees' verifiable claims were verified by referring to the research literature and Government of India documents, and those for which little to no evidence was found are presented with a disclaimer.

III. Findings and Discussion

Regenerative Practices

The following principles have been grouped and presented based on the information collected on the operations of Auroville farms.

The sourcing of water is a key pillar to consider in sustainable agricultural practices. Whether it is borrowed from neighboring farms or extracted from groundwater reserves, the method of harvesting water and utilizing it most optimally (with practices such as micro-irrigation) involves considering plants' needs, rather than irrigating as per the convenience of the cultivator. Within this are two more parameters: the specific needs of the crop (a trivial example is how most vegetables generally need 2 liters of water per day), and the optimal timing of irrigation so as to avoid loss of moisture due to evaporation (often this is early morning or after sunset). Certain key regenerative practices like organic mulching, which uses plant waste and will be discussed more in detail later, may also be employed to retain moisture.

The ***type of soil*** on which the field is situated is the second consideration. Conservation tillage is a practice that reduces the amount of tillage to conserve the soil and leverage existing moisture. Integrated nutrient management focuses on reducing nutrient losses by controlling erosion and emphasizes the need for fixation of nitrogen within the farm system (as opposed to importing nutrients.) Soil is interlinked with water considerations. Illustratively, an irrigation pond is suggested to be an expensive idea when situated on porous soil, by virtue of the latter not being able to retain water in porous conditions. Percolation methods, involving digging small pits and recharging the aquifer, could instead maximize efficient water usage.

The aspect of the appellation of regenerative agriculture which sparks the most interest in itself is 'regenerative.' The process of regenerating barren land is described as beginning with simple irrigation. The idea is to irrigate and let any plant life grow, as natural processes will have inevitably brought seeds onto the cultivation field. These can serve as organic mulch for the next crop, and also serve to indicate the suitability of the growing conditions for specific plants, so that which plants grow well on the soil are noted. Fast-growing mulching plants which take approximately forty days to mature may be cultivated for use as secondary mulch; this is known as green manuring (National Centre for Organic and Natural Farming, n.d.). (Sowing outsourced plants may serve as alternatives, though outsourcing should be limited in regenerative systems; outsourced hemp, for example.) The mulch is sustained by a 'chop-and-drop' method every 1.5 months; this will allow the plant to continue regenerating and the chopped parts to serve as mulch. To produce fertility sustainably, it is advantageous to be familiar with the soil types (red, sandy, loamy, black, laterite, etc.) and their usual regions of abundance, as their capacity to hold nutrition and moisture are a factor in sustainable systems design. Fostering fertility amounts to increasing microbial biodiversity in the soil. Mulch provides the shade, low temperature, moisture, and sugary source of nutrition that enrich microbes, thus being central to soil care in regenerative practices.

Production in Auroville involves making careful, educated choices of seed types. One approach employed includes experimenting with seeds, which may be sourced from anywhere, then allowing them to grow on a 400 square foot area to observe how they perform on the conditions of the specific soil. This will highlight the challenges faced in the cultivation of this particular species; the season, soil, nutrition, or particular diseases and pests may not be suitable. Filtering the best seeds from this lot, these are replanted in a second cycle on a larger scale (e.g., 0.05 acres.) In the third cycle one acre is the target, all while self-producing the seeds. The regenerative principle is that the seeds must be selected and trained for the conditions of the land to obtain better results. This makes them resilient in the process. By the fifth generation the seed's capacity and whether it is appropriate for commercial production will be apparent. Eventually, for a farm to truly be regenerative, it must generate its own seeds. Labor expenses are another consideration in production. In choosing between raised bed and plot models for a farm, a raised bed model is virtually permanent and does not require labor to redo the plots, which have to be reshaped and plowed after every crop. Minimizing these recurring expenses is one principle in the regenerative framework.

In a similar vein of trial and testing, pest control may be initially managed with externally-sourced organic inputs to observe their efficacy, after which the farm must produce its own inputs. Gradually, it can reduce the frequency of pesticide and fertilizer applications until the inputs are halted completely, to make the farm resilient and self-sustaining, inviting pest-controlling predators and improving soil health to prevent disease. 20% of the crop is cited by the Auroville farm as a necessary sacrifice to allow a biodiversity of predators to eat pests. The process of these informal trials must be documented so that improvement upon and adaptation of the same for localized conditions are possible. For example, copper sulphate, a fungicide, may initially be used to treat a fungus attack. Building on this, fermented garlic extract, which contains this compound, may be sourced from around the farm. But as this is cost-intensive, a fermented coconut milk and buttermilk mixture may serve the purpose better. The guideline of self-sustenance warrants cost-cutting by experimenting with farm-sourced inputs. A particular example from Auroville is the shift to sprinkler irrigation for brinjal, which are prone to borer attacks. This has the benefit of trapping the moths by wetting their wings (preventing them from laying borer eggs) as well as washing off the remaining eggs. Merely by changing irrigation methods the pest attacks were reduced by roughly a third.

Energy tends to be the most cost-intensive pillar of farm production. Renewable energy is expensive and is ideally integrated after five years of operation, once capital has been accumulated to invest in it. For the first five years a farm may reasonably depend on the government to source electricity. In the long-term however, such dependency thwarts sustainability. While carbon-oriented farming is a sustainable path focused on improving carbon content in soil, nitrogen-based farming requires significantly more energy, labor, and inputs. Carbon in and of itself improves water retention, nutrition, and almost all aspects required for cultivation.

For a regenerative farm to become full-fledged, however, it takes between two and five years. An obvious drawback of these techniques are the initial dependence on external sources (the system is not self-contained) and the prolonged timeframe in which commitment is required, meaning they have to be evaluated for each local circumstance.

Policies and Context

Farmers

A brief survey of the farmer's perspective provides context to the techniques discussed above. One specification are the obstacles, which are by no means exhaustively reviewed below, but generally identified from the results of the interviews.

I. Standardization.

- As per the interviewed sources, organic farming methods are often at the discretion of farmers and are not practiced with respect to many standardized procedures. They also usually completely disregard securing an organic certificate and rely on their network and word-of-mouth to build trust in local markets and sell their produce as organic.
- This is fairly effective for local marketing. However, a certificate is necessary to export organic produce, and this requires considerable funding. International markets are also the foremost incentive for farmers to opt to practice organic farming over other sustainable methods; a certification already exists for it which is easily recognizable by consumers.
- Nevertheless, organic farmers struggle to obtain a good price for organics domestically—the phenomenon is catching on among urban consumers but the demand is still localized in niche markets, but whether this is because certificates are not widely recognizable or not granted to enough farmers is not clear.

II. Labour intensiveness.

- Sustainable agricultural systems are still not mainstream, so there is limited mechanization for their unique methods. They are thus labor-intensive, a setback in their adoption by larger scale farmers.
- The obstacle is often scale and initial investment: agroforestry, for example, is usually only done on large plots, so it is not a choice for most small farmers.

III. Geographical non-uniformity.

- The issues caused by chemicals also vary for different crops, suggesting that the consequences of a sustainable transition, both on the environment and the farmer, depend on the farmer.
- An FPO representative illustrated that for Assamese groundnut cultivation, chemical usage is not very intensive. The region experiences heavy, often unpredictable precipitation, so the application of pesticides and similar chemicals appear pointless and wasteful when the farmer does not know when heavy rains may come to wash them away.
- In paddy cultivation however, yield is the primary objective, so there is heavy consumption of fertilizers and pesticides. In this case it is much more fruitful to find ways to make paddy cultivation sustainable.

IV. Policy Recommendations

Only eight of the sixteen sustainable farming methods identified by a study by the Council on Energy, Environment, and Water receive budgetary allocation from the Indian government. In 2021, organic farming was the method receiving the most funding and administrative focus (Pradhan et al., 2021). [3] Although significant strides towards sustainability in agriculture are apparent, the synthesized results of the interviews reveal areas for improvement.

Provision vs. process support. As per the interviewee, stakeholders are better served by government support for training and processes than the efforts currently focused on providing and subsidizing fertilizers and inputs. Indeed, an OECD report points to potential gains from scaling back variable input subsidies and reinvesting them in training farmers in the sustainable and efficient use of the inputs (OECD, 2022). The same report highlights negative support and implicit taxation as payments to farmers failed to offset the costs of byzantine trade policy and domestic market regulations. The provision of inputs is limited in efficacy for two reasons: farmers and cultivators require competence in methods more critically than material assistance, for this is the root of the current system, and many Indian farmers have little to no funds so that even subsidized inputs are out of reach. Farmers require encouragement and support to develop farms that are both regenerative and self-sustaining. The inputs are better off being provided for an incubation period, where the farmers are supported for the first three years, and then withdrawn once they have a sustainable operating farm. Rather than loans, grants to establish revenue-generating farm units can further this aim as well. To the same effect, small technical centers near the farms can be subsidized. Having organic farming experts and technicians located at these nearby centers to assist the farmers when required can help in the skill-building required for a long-term solution to the problems faced in conventional farming.

Buybacks and forecasting. A buyback in place of a minimum price can be of better benefit to farmers. The prices that farmers receive are often below breakeven. The government's macroscale calculations for production often do not align with real market prices, and the sufferers are small-scale farmers who overproduce. A model of self-management and self-government where every small panchayat confers with government officials

[3] The sixteen practices are: Organic Farming, Natural Farming, Agroforestry, Biodynamic Agriculture, System of Rice intensification, Precision Farming, Conservation Agriculture, Crop Rotation and Intercropping, Cover Crops and Mulching, Integrated Pest Management, Vermicomposting, Contour Farming, Integrated farming Systems, Rainwater Harvesting, Floating farming, and Permaculture.

about the levels of consumption, demand, and production, to forecast and plan can make these buybacks possible and effective. Handholding, guidance, and forecasting are a more result-oriented alternative to funding and freebies. Every panchayat could have a coordinated team, and these teams and conferences should be facilitated by the government.

Alternatives to Certifications. The use of certifications is limited, as they are costly, require much persistence in following-up from the farmers' side, must be renewed annually, and are perceived by farmers and consumers to hold little esteem or value according to one organic produce company. Most farmers are understandably not educated on this serpentine process. The legitimacy of the certification is also in question as some certified farms reportedly buy inorganic and sell it as organic, which is a concern given that customer trust and relationships govern most market transactions in produce and commodity markets. Often consumers identify organic produce through their taste. Developing a culture of organic consumption and the expanding scope of availability of organic products are the only effectual solutions to this. The government must create organic models which are productive to provide persuasive examples for farmers to switch. An interviewee expressed ambiguously that certain private entities currently do this, but this should ideally come from the government.

Regional Officers. The demands of each region and the capacities of each climate and soil type must be better accounted for to efficiently allocate and organize production. Currently, most farmers produce what they are willing or able to and sell it through cooperatives. Production needs to be further streamlined to observe and match consumption as best as possible. A direct relationship between consumer and farmer, without mediation, is also imperative to this process. One approach is if an agriculture officer assigned to every region supervises production and can testify that the region produces organically. Currently government-employed agriculture officers are not associated with each region. After a period of ten years or so, farms can be weaned off the support of these officers and the officers will cease to be an expense on the budget.

V. Conclusions

The results show that the process to support a transition to sustainable methods, though not nonexistent, has not been given the time and resources it requires. Even once the transition has been initiated, the fruits of sustainability will only be born later—the soil and seeds must be conditioned, and there is a significant time commitment for results to be seen. By and large in India, sustainable methods could be dynamic and adaptable to the diverse circumstances of individual farms, but at the same time they lack a rigid framework of classification for widespread usage and targeted policy intervention. As the still-unsatisfactory prices and haphazard production levels of farmers shows, policies must be recalibrated to serve their precise needs in each region—an approach focusing more on institutional support and training and scaling back direct provisions. A survey of the evidence does not promise that even the substantial potential increases in yields discussed above will suffice to match population growth, but it remains the most viable option given the multidimensional benefits. The key extrapolation is that with accelerated widespread adoption and further innovation in sustainable practices, productivity can improve.

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