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Agronomic interventions for doubling farmer's income

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Abstract

Agriculture plays a pivotal role in sustaining the livelihoods of over half of our country's population, thanks to modern and effective technologies. However, the advent of innovative technologies has inadvertently exacerbated income inequality within the farming community. These advancements tend to benefit semi-medium to large-scale farmers more than their small and marginal counterparts. In light of this, Prime Minister Shri Narendra Modi has set forth a vision to double farmers' income by the year 2022, coinciding with the 75th anniversary of our nation's independence. Doubling farmers' income by 2022 is undoubtedly a challenging endeavor, but it is both necessary and achievable. This ambitious goal can be realized through various agronomic interventions, including crop diversification, the adoption of conservation agriculture practices, efficient utilization of nutrients and water resources, and the cultivation of region-specific improved crop varieties. Additionally, government programs aimed at supporting farmers in these initiatives play a crucial role in this process. The overarching objective of doubling farmers' income is to promote their welfare, mitigate agrarian distress, and bridge the income gap between farmers and those employed in non-agricultural professions. This paper provides a comprehensive review of the strategies required to achieve this goal, outlining the steps and measures necessary to uplift the farming community and enhance their economic well-being.

Keywords: Innovative technology, pivotal role, effective technology, doubling farmer's income

Introduction

Indian agriculture contributes 8% to the global agricultural gross domestic product (GDP), supporting 18% of the world's population with only 9% of the world's arable land and 2.3% of its geographical area. Approximately one-fourth of the country's population lives below the poverty line, and roughly 80% of our landmass is highly susceptible to droughts, floods, and cyclones. On a positive note, India boasts significant biodiversity, with nearly 8% of the world's documented animal and plant species residing here. Many of these species are crucial for the livelihood security of the impoverished and vulnerable populations. Therefore, conserving natural resources, preserving biological diversity, and accelerating agricultural growth are deemed critically important both now and in the future.

Historically, the development strategy for India's agriculture sector has primarily focused on increasing agricultural output and improving food security. This strategy proved successful in addressing severe food shortages that emerged in the mid-1960s. While the country achieved commendable food production levels, farming itself gradually became unprofitable due to rising costs and uneconomical land holdings. The distressing conditions faced by farmers across the nation have severely shaken the agricultural foundation. This strategy did not explicitly acknowledge the need to raise farmers' incomes and did not include any direct measures to promote their welfare. Data from the National Sample Survey Office's Consumption Expenditure Survey for 2011-12 revealed that more than one-fifth of rural households engaged in agriculture as their primary occupation had incomes below the poverty line. Some states had even higher proportions of farm households living in poverty, with Jharkhand having the highest incidence at 45.3%.

During the early 1980s, the income of a farmer per cultivator was only 34% of the income of a non-agricultural worker. This significant disparity required a policy response to increase farmers' incomes more rapidly. The low and highly variable farm income is discouraging interest in farming and investments in the sector, leading more cultivators, particularly younger individuals, to abandon agriculture. This trend could have serious adverse effects on the future of agriculture in the country.

Recognizing the need to address the challenges faced by farmers, the Central Government changed the name of the Ministry of Agriculture to the Ministry of Agriculture and Farmers' Welfare in 2015. It is evident that the income earned by farmers from agriculture plays a crucial role in addressing agrarian distress (Chand, 2016) [1] and promoting farmers' welfare. Against this backdrop, the goal set by Prime Minister Shri Narendra Modi to double farmers' incomes by 2022-23 is central to promoting farmers' welfare, reducing agrarian distress, and bridging the income gap between farmers and those employed in non-agricultural professions. The Inter-ministerial committee constituted by Government of India, recommended the following strategies for doubling farmer's income: (i) improvement in the crop productivity; (ii) improvement in the livestock productivity (iii) resources use efficiency or savings in the cost of production (iv) Increase in the cropping intensity and (iv) diversification towards high value crops (NITI, 2017) [4].

In order to enhance the income of the farmers, and reduce the production cost by increasing the input use efficiency, the agronomic interventions *viz.*, integrated farming systems, crop diversification with remunerative crops, site specific nutrient management, conservation agriculture, micro-irrigation etc are very important approaches (Bussa and Prasad, 2019) [5]. These agronomic strategies have the potential to double the farmer's income with the rise of new innovations in agricultural technologies. The widening income gap among various segments of the farming community favors medium and large-scale farmers who are more inclined to embrace new technologies. Increasing farmers' incomes and ensuring their income security have thus become concerns for everyone. Without a substantial increase in farmers' incomes, we cannot effectively address distress (Chand, 2016) [1].

Before tackling the challenge of doubling farmers' incomes, it is essential to understand the issues faced by the agriculture sector in India. These challenges include the declining average size of land holdings, with around 85% of farmers being small and marginal, 60% relying on rainfed cultivation susceptible to monsoon fluctuations, the depletion and deterioration of natural resources, yield plateaus in most crops, deficiencies in multiple nutrients, poor total factor productivity, the impact of climate change, limited resources available to the majority of farmers, and food losses ranging from 5% to 25% across the entire supply chain. Additionally, the slower growth in the agriculture sector raises concerns about the future food and nutritional security of the country. Overall, effective management of natural resources is the most critical challenge.

Increasing Productivity of Farm

Enhancing agricultural productivity plays a crucial role in ensuring food security. One effective approach to reducing the required land for farming and mitigating environmental damage and climate change, such as deforestation, involves increasing agricultural productivity through sustainable methods. This boost in productivity can be attributed to advancements in agricultural techniques and technological innovations. Various strategies have been employed to achieve improvements in agricultural productivity, as outlined below.

1. Crop Diversification and Intensification
2. Efficient Rainwater Management
3. Integrated Crop Management (ICM)
4. Climate Smart Cropping
5. Crop residue management
6. Conservation Agriculture (CA)
7. Efficient Residue Management
8. Increasing Cropping Intensity/Land Use Efficiency
9. Integrated Farming Systems (IFS)
10. Improvement in seed replacement ratio/rate etc.

Crop Diversification and Intensification

Crop diversification involves introducing new crops or farming systems to a particular farm, taking into account their varying yields and potential for added market opportunities. Agricultural diversification can enhance crop productivity and provide multiple ecological benefits by adopting diverse farming practices like crop rotation, multiple cropping, intercropping, orchards, and agroforestry. These methods allow farmers to leverage biological cycles to reduce production inputs, preserve natural resources, optimize yields, and minimize ecological and environmental risks. This presents a significant opportunity to boost income and employment in rural communities.

Crop diversification fosters beneficial interactions with soil bacteria, disrupts disease cycles, and reduces weed populations. It enhances land utilization and crop yields by improving soil physical and chemical properties. Additionally, crop diversification offers various avenues to address issues such as pest and weed outbreaks, soil degradation, environmental pollution, soil salinity, declining farm productivity, and the impacts of climate change. Consequently, crop diversification is well-suited to achieve objectives such as food security, income growth, employment generation, and sustainable agricultural development. Crop diversification strategies -

- Shifting from low value crops to high value crops.
- Shifting toward high water requirement crops to low requirement crops.
- Shifting toward low energy efficient crops to higher energy efficient crops.
- Inclusion of legumes and oilseed crops in prominent cropping system

Table 1: Most of the evidence showed that diversification of traditional cropping practices increase the benefit cost ratio.

S. No.	Traditional cropping system (TCS)	B:C ratio of TCS	Diversified cropping system (DCS)	B:C ratio of DCS	Reference
1.	Rice-Coriander-Green gram	1.89	Rice-Lentil-Green gram	2.38	Roy *et al.*, 2011 [22]
2.	Rice-wheat	1.44	Maize (cobs) + vegetable cowpea + *Sesbania* (BBF: 105 cm wide bed and 30 cm wide furrow, *Sesbania* in furrow and incorporation at 42 days after sowing.	2.86	Wallia *et al.*, 2022 [24]
3.	Rice−Wheat	1.29	Maize−Cole crops−Sesame	3.63	Upadhaya *et al.*, 2022 [25]
4.	Rice-Green gram-fallow	0.96	Rice-Cabbage-Bottle gourd	4.50	Arvadiya *et al.*, 2018 [18]
5.	Pearl millet-Mustard-Fallow	0.83	Green gram - Fennel+ Cauli Flower-Fennel	3.06	Patel *et al.*, 2018 [21]
6.	Rice-Rapeseed-Fallow	1.56	Rice-Pea-*Dhaincha* (GM)	2.16	Kalita *et al.*, 2020 [20]

Integrated Farming System (IFS)

Integrated Farming Systems (IFS) involve the adoption and incorporation of a wide array of resource-efficient practices to ensure that farms generate satisfactory profits while maintaining economic sustainability. This approach also focuses on ecological renewability, social acceptability, mitigating negative impacts associated with intensive farming, and preserving and enhancing the environment. The Integrated Farming System approach places particular importance on diversifying cropping and farming systems, which has proven to be successful in improving the economic well-being of small-farm households. This achievement is made possible by implementing cost-effective technologies to narrow yield gaps and integrating low-input-demanding enterprises to holistically develop farms, thereby ensuring livelihoods and nutritional security.

This approach has been effectively implemented on small land holdings ranging from 0.4 to 1.5 hectares, successfully meeting various household needs such as food, fodder, feed, and fuel. It also achieves goals such as reducing production costs, increasing profits, and ensuring nutritional security, creating more employment opportunities, providing a stable income, and safeguarding the environment. Promising enterprises integrated with existing farming systems include horticultural crops like fruits and vegetables, as well as fishery, goat farming, poultry, duck farming, and pig farming, which have significantly increased income (by 200% to 450% or more). Recycling and periodic use of products and by-products within the system can lead to substantial cost savings, often exceeding 45%. The diversified nature of IFS, which requires more labor, contributes to generating more job opportunities for rural youth. Additionally, reduced chemical usage in IFS not only decreases health hazards but also lowers environmental pollution.

Table 2: IFS: Expected Outputs in Sustainable Way

S. No	Expected output	Profit
1	Productivity gains	2-3 times
2	Gain in net returns	3 to 5 times
3	Resource saving	40-50%
4	Average regular net daily income	Rs 800/household of 1 ha
5	Additional Employment generation	70 to 80%
6	Lower emissions of GHG	20-40%
7	Household nutritional security	100%

***Source*:** IIFSR, 2017

Integrated Crop Management (ICM)

Integrated Crop Management (ICM) is a sustainable practice that emphasizes the preservation and enhancement of natural resources in the production of high-quality food. It offers a holistic approach to enhancing crop production and protection, encompassing strategies for weed, pest, and disease management, soil fertility improvement, efficient water utilization, and post-harvest handling. These strategies may involve the judicious use of fertilizers, planting in organized rows, consistent irrigation, intercropping with other plant varieties, and the adoption of improved crop varieties suited to different agroecological conditions.

ICM is tailored to specific cropping systems, environmental conditions, and the socio-economic status of farmers. It addresses various challenges, such as land degradation and soil erosion, the enhancement of soil fertility, the efficient application of fertilizers, the promotion of genetic diversity, effective pest and disease control, and the prevention of deforestation to increase agricultural productivity.

ICM is founded on four core principles. They are:

(i) Integrated Disease Management (IDM)

Integrated Disease Management (IDM) can be described as a decision-driven approach that strategically combines various methods to achieve effective and economically sound pathogen control while considering ecological factors. IDM typically involves research to determine the most appropriate combination of strategies and tactics, applied at the right time. These strategies encompass a range of practices, including selecting suitable sites, using resistant crop varieties, altering planting techniques, modifying the environment through activities like drainage, irrigation, pruning, thinning, shading, and, when necessary, employing pesticides.

In addition to these conventional measures, IDM places significant importance on monitoring environmental conditions such as temperature, humidity, soil pH, and nutrient levels. Disease forecasting and the establishment of economic thresholds also play a crucial role in IDM conservation management plans. All these measures should be implemented in a coordinated, integrated, and harmonized manner to maximize the effectiveness of each component. For instance, optimizing the balance between fertilizer application and irrigation methods can promote the growth of healthy and robust plants. However, achieving this balance is not always straightforward, and disease control may become reduced to isolated measures that closely resemble traditional disease control methods. Regardless of the specific measures employed, they must align with the agricultural practices associated with the particular crop being managed.

(ii) Integrated Pest Management (IPM)

Integrated Pest Management (IPM) represents an environmentally conscious and highly efficient approach to pest control. It relies on a combination of established practices and relies on a comprehensive understanding of pests' life cycles and their interactions with the environment. This knowledge, coupled with existing pest control methods, is leveraged to mitigate pest damage in a manner that is both cost-effective and minimizes potential risks to people, property, and the environment. The IPM approach can be implemented not only in agriculture but also in various settings such as homes, gardens, and workplaces. It encompasses all suitable pest control strategies, including but not limited to the prudent use of pesticides. In contrast, organic food production shares many of the fundamental principles of IPM but places restrictions on the use of pesticides, emphasizing natural sources over synthetic chemicals.

(iii) Integrated Nutrient Management (INM)

INM, or Integrated Nutrient Management, aims to enhance crop productivity and sustain soil fertility for future generations by combining natural and artificial soil nutrients. Instead of concentrating solely on a single crop, INM strives to optimize nutrient usage within a crop rotation or cropping system. This encourages farmers to engage in long-term planning and consider environmental impacts. INM encompasses various aspects, including proper nutrient handling, storage, and the dissemination of knowledge about INM practices among farmers and researchers.

To enhance plant nutrient availability, several techniques are discussed in this guide, such as embankment, street cultivation, protective measures, and crop rotation. As these methods are elaborated on elsewhere in this guide, this section specifically focuses on INM concerning the appropriate application of fertilizers. Beyond traditional fertilizer selection and application, INM practices encompass innovative approaches like deep placement of fertilizers and the utilization of inhibitors or urea coatings. These advancements are designed to improve nutrient absorption by reducing the activity and growth of bacteria responsible for denitrification.

(iv) Integrated Weed Management (IWM)

Integrated weed management involves the strategic use of multiple control strategies, reducing the overreliance on herbicides and increasing the likelihood of successful weed control or elimination. To effectively manage a significant lanthanum infestation in pastures on a large scale, an integrated weed management program would include the following steps:

a) Temporary removal of weed plant parts for several months.
b) Timing-appropriate actions, such as controlled burning (or substituting with bulldozing or slashing where terrain and access permit), to reduce the bulk of mature plants.
c) Early summer seeding of improved pasture.
d) Continued exclusion of livestock until the new pasture establishes.
e) Subsequent herbicide spot spraying on regrowth.
f) Repeating this comprehensive approach for 2 to 3 years.

This integrated approach necessitates careful planning, a solid understanding of weed biology and ecology, and the selection of appropriate weed control techniques.

Conservation Agriculture

Conservation Agriculture (CA) is a farming approach that serves as a solution to preventing the loss of arable land and revitalizing degraded lands. It emphasizes the maintenance of a permanent soil cover, minimal disturbance of the soil, and the introduction of a variety of plant species. CA promotes biodiversity and enhances natural biological processes both above and below the soil surface. This, in turn, leads to improved water and nutrient utilization efficiency and sustainable crop production.

CA promotes sound agronomic practices, including timely operations, and enhances overall land management for both rain-fed and irrigated farming. When combined with other established best practices such as using high-quality seeds and implementing integrated approaches to manage pests, nutrients, weeds, and water, CA forms the foundation for sustainable agricultural intensification. It also creates opportunities for integrating various production sectors, such as combining crop and livestock farming or incorporating trees and pastures into agricultural landscapes. Three fundamental principles underlie conservation agriculture: (i) minimizing soil disturbance, (ii) maintaining continuous residue cover, and (iii) implementing crop rotation or using cover crops. These principles are interconnected and reinforce one another.

The adoption of conservation agricultural technology has been shown to reduce labor requirements by up to 34%, seed usage by 31%, fertilizers by 6%, pesticides by 32%, and overall production costs by as much as 10% when cultivating crops like lentils, mustard, maize, and wheat. Furthermore, this adoption has led to significant increases in crop yield (up to 28%) and net profit (up to 43%). Propensity score matching (PSM) methods have further confirmed the substantial positive impacts of CA technology adoption, including increased crop yield, reduced variable costs, and higher net income for adopters (Miah *et al*., 2023) [9].

Precision Land Levelling

Precision soil leveling using a scraper involves the process of accurately smoothing the soil's surface to be within a range of ±2 cm of its average micro-height. The complete laser leveling equipment comprises various components, including a laser transmitter, laser receiver, two-way hydraulic valve, laser loop, leveling stick with a base, tractor control box, and the scraper itself.

The laser transmitter emits a continuous self-leveling laser beam signal in a 360° pattern, which covers a command radius of 300-400 meters (depending on its range). This laser signal is crucial for automatically controlling the receiving device. The laser transmitter is typically positioned on a stand located outside the working area, ensuring that it is both level and elevated enough to allow the laser beam to travel without obstruction. The laser receiver, installed on the scraper, is a unidirectional receiver that captures the laser reference plane's position. It then communicates this information to the control panel mounted on the tractor. Additionally, a control-double hydraulic valve is used to direct the scraper blade's up and down movements, ensuring that the soil is leveled evenly.

Climate Smart Cropping

In the context of a changing climate, it becomes increasingly important to develop crop varieties that are resilient to the effects of climate change as a means of maximizing the efficient use of resources. For instance, cultivating crop varieties that are resistant to lodging, such as shorter rice cultivars, can withstand strong winds during critical stages of crop growth, providing a viable alternative. Similarly, adjusting planting dates to mitigate the impact of rising temperatures and reduce spikelet sterility can enhance yield stability. This is achieved by avoiding the flowering period coinciding with the hottest periods. These adaptation measures, including altering the crop calendar to minimize the adverse effects of increased climatic variability in arid and semi-arid regions, have proven advantageous in avoiding extreme weather events like typhoons and storms during the growing season, as highlighted by Vyas *et al.,* in 2017 [10].

Emerging evidence suggests that the adoption of climate-smart agriculture (CSA) practices can help smallholder farmers adapt to climate change while also boosting agricultural productivity, leading to increased household income and food security. In a recent study conducted by Belay *et al*. in 2023, it was found that farmers who embraced CSA practices had significantly higher food consumption scores (between 6.27 and 8.15) compared to non-adopters. Furthermore, households that adopted CSA practices reported a 20.30% higher average annual farm income per hectare when compared to those who did not adopt these practices, demonstrating the tangible benefits of CSA adoption.

Increasing Cropping Intensity/Land Use Efficiency

To meet the growing demands for food and other resources due to the increasing population, there are primarily two approaches: expanding the cultivated land area or intensifying cropping on existing land. The total cultivated area in the country has expanded by approximately 20% since gaining independence, but it has now reached a point where significant further expansion is not feasible. Consequently, the most viable option remaining is to increase cropping intensity.

Cropping intensity refers to the practice of cultivating multiple crops within the same field during a single agricultural year. Higher cropping intensity signifies that a larger proportion of the cultivated land is used for more than one crop within the same agricultural year, leading to increased productivity per unit of arable land. In many states, the second crop is planted on less than one-fourth of the total cultivated land. The primary reason for this low cropping intensity is often the limited access to water resources needed to meet the requirements of multiple crops. However, post-2000, there has been a gradual annual increase of 0.7% in cropping intensity across the country. There is significant potential to further raise cropping intensity in most states.

Initiatives like "Har Khet Ko Pani" and other components of the "Pradhan Mantri Krishi Sinchai Yojana" offer promise in rapidly expanding irrigation facilities, which would greatly contribute to increasing cropping intensity. If cropping intensity continues to increase at the same rate observed in recent years, it has the potential to raise farmers' income by 3.4% in 7 years and 4.9% in 10 years. Moreover, these figures could be even higher given the brightening prospects for cultivating second crops, as indicated in Table 3.

Table 3: Rice – Fallow areas' to be enhanced

States	*Kharif*-Rice Area ('000 ha)	*Rabi*-Fallow (RRFL) ('000 ha)	% of RRFL in India
Chhattisgarh +M P	5.60	4.38	78.21
Bihar +Jharkhand	5.97	2.20	36.85
West Bengal	4.62	1.72	37.44
Orissa	3.88	1.22	31.44
Maharashtra	1.76	0.63	35.80
Assam	2.23	0.54	24.22
Andhra Pradesh	2.66	0.31	11.65
Uttar Pradesh	6.62	0.35	5.29
Others	7.20	0.30	4.17
Total	40.18	11.65	29.00

Source: Singh *et al*., 2016

Efficient Rainwater Management

Rainwater serves as the primary source of water for agriculture, yet its current efficiency in crop production ranges only between 30% and 45%. Annually, a significant amount of seasonal rainfall, ranging from 300 to 800 mm, goes unproductively used as it either turns into surface runoff or deep drainage. Efficient utilization of rainwater involves the conservation of this valuable resource and can be achieved by making informed choices regarding crops, utilizing improved varieties, adopting appropriate cropping systems, and implementing nutrient and pest management practices that enhance productivity while preserving natural resources.

Rainwater harvesting can be categorized into two main types:

a. **In-situ Rainwater Harvesting**:

This approach focuses on altering soil and water management techniques to improve soil infiltration, water retention capacity, fertility, and counteract soil erosion. Various types of barriers are used to capture rainwater runoff in sloping fields, storing it in the soil for immediate use by crops. The capture and storage areas are in close proximity. In-situ rainwater harvesting primarily enhances water intake at three levels: soil surface (through diverting surface runoff), rooting zone (for plant water uptake), and groundwater (for groundwater recharge). Practices include contour cultivation, conservation furrows, broad bed and furrows, mulching, and off-season tillage, among others.

b. Ex-situ Rainwater Harvesting

In this method, rainwater is collected and stored for various productive purposes, such as drinking water, agriculture, and sanitation. Ex-situ systems capture rainwater from catchment areas like rooftops, land surfaces, steep slopes, road surfaces, or rock catchments. This collected water is then directed to storage points, which can be natural or artificial reservoirs of different types, including wells, farm ponds, basins behind dams, tanks, or cisterns. Unlike in-situ harvesting, ex-situ systems are used when the capture surface has limited or no infiltration capacity. Rooftop rainwater collection is a common example of ex-situ rainwater harvesting. Implementing ex-situ systems can alleviate pressure on surface water and groundwater resources, mitigate peak flows, and affect flow durations positively.

Improvement in Seed Replacement Ratio/Rate (SRR)

Seeds play a pivotal role in agricultural production, significantly influencing the performance and effectiveness of other farming inputs. To enhance productivity, it is essential to have access to quality seeds that are suitable for specific agro-climatic conditions and available in sufficient quantities at affordable prices. The seed replacement rate, which measures the proportion of old seeds replaced with new ones, continues to remain low, ranging from 2-10% in certain states and for specific crops. This falls well below the desired level of 20% for most crops. It is widely recognized that the seed replacement rate is closely linked to crop productivity and production levels.

The adoption of superior planting materials, such as the use of hybrids or high-yielding varieties (HYV), has been a persistent challenge. The seed replacement rate directly affects the proportion of cultivated land that benefits from quality seeds. Therefore, it has a direct impact on increasing agricultural productivity, boosting farmers' income, and serves as one of the strategies to achieve the goal of doubling farmers' income.

Reducing Cost of Cultivation

Farmers can reduce the cost of crop cultivation and make agriculture a more profitable endeavor through the adoption of modern agricultural practices, efficient farm planning, and diversified production based on market demand, and improved access to local and distant markets. These strategies can also enable farmers to explore additional working hours. To achieve cost reduction in cultivation, the following methods can be employed:

- Resource conservation technologies (RCTs)
- Promoting low or no cost inputs
- Low input farming system
- Enhancing resource use efficiency

Low Input Farming System

Low Input Farming Systems (LIFS) are designed to optimize the management of on-farm resources and minimize the use of off-farm resources, such as purchased fertilizers and pesticides, whenever possible and practical. The primary objectives of LIFS are to reduce production costs, prevent surface and groundwater pollution, decrease pesticide residues in food, lower a farmer's overall risk, and enhance both short and long term farm profitability. These systems aim to utilize external inputs only to address deficiencies in the ecosystem and improve available biological, physical, and human resources. When external inputs are used, the focus is on maximizing recycling and minimizing adverse environmental impacts. Rather than aiming for maximum short-term production, LIFS prioritize achieving stable and sufficient production levels over the long term.

Low Input Farming Systems encompass a range of approaches, including extensive mixed farming, grassland systems, sylvopastoralism, organic farming, and integrated farming, among others. These systems are often adopted for two main reasons: either due to environmental limitations, such as in mountainous areas, or as a conscious choice by farmers seeking autonomy, better health, and environmental benefits. Economic considerations may also play a significant role. LIFS are well-suited to deal with price fluctuations in agricultural commodities since they are less dependent on external inputs.

Resource Conservation Technology

Resource Conservation Technology, often referred to as Resource-Efficient Agriculture, is a scientifically grounded agricultural approach that employs technologies aimed at preserving and efficiently utilizing natural resources. The primary objectives are to enhance production and productivity while simultaneously safeguarding the environment. This method seeks to conserve, enhance, and optimize the utilization of natural resources, integrating the management of soil, water, and biological resources with external inputs. Resource Conservation Technology plays a vital role in environmental preservation and the promotion of sustainable agricultural production. It can also be termed as resource-saving or resource-effective agriculture. Some key resource-saving technologies include:

Zero or Minimum Tillage

No-tillage is a farming practice where seeds are directly planted into the soil without plowing, while retaining the residues of the previous crop. The main objective is to minimize soil disturbance to prevent weed seeds from surfacing and initiating germination. This approach, known as zero tillage, has several benefits, including improved soil structure and reduced erosion. When implemented correctly, zero tillage can enhance soil structure by increasing the presence of biochannels and macrospores, reducing vulnerability to compaction, and promoting soil uniformity. The improvement in soil structure associated with no-till farming fosters robust biological activity in the soil.

Over the past decade, zero-tillage technology has gained popularity, especially in Northwest India. In 2008, the rice-wheat cropping system in India saw 1.76 million hectares of land adopting no-tillage or reduced tillage practices. Zero seeding of wheat offers advantages such as efficient water utilization, reduced reliance on irrigation, and conservation of irrigation water. This is particularly significant in the Indo-Gangetic plains, where water scarcity is already a pressing issue.

Mulching

Mulching is an agricultural practice involving the placement of a protective cover over the soil surface, other than soil or live vegetation, to promote soil and water conservation and support plant growth. This practice has been successfully employed in various settings, including agricultural lands, areas affected by fires, rangelands, and human-altered sites, to reduce soil and water losses. Soil erosion by water is a particularly concerning issue, especially in semi-arid and semi-humid regions worldwide. While the benefits of mulching are acknowledged, further research is required to quantitatively assess its impact, particularly in areas where water-induced soil erosion poses a significant threat. Some uncertainties still exist in the literature regarding how to optimize the effectiveness of mulching in reducing soil and water loss rates.

Recognizing the severity of water-induced soil erosion and the ongoing uncertainties surrounding the proper use of mulching, this review study aims to achieve the following objectives:

(i) Compile a comprehensive global database on the use of mulching with vegetative residues
(ii) Quantify the effects of mulching on soil and water loss through various measurement methods and at different spatial scales
(iii) Assess the impact of different types of mulches on soil and water losses using diverse measurement methods
(iv) Offer recommendations for more sustainable soil management practices.

The study finds that mulching has beneficial effects in mitigating soil erosion by water across various environments, with reduction rates in average sediment concentration, soil loss, and runoff volume, sometimes exceeding 90%. However, information on the economic feasibility of mulching applications is limited in the literature. Therefore, further research is essential to provide evidence-based guidance for both farmers and land managers seeking to implement sustainable soil management practices.

Nutrient Responsive Variety

Plants that serve as food crops contain a wide range of biologically active compounds that contribute to human health in various ways. While people in industrialized countries typically have access to nutrient-rich food crops, the same cannot be said for many rural communities in developing nations. These populations often struggle to maintain a balanced diet with sufficient levels of vitamins and minerals. In many cases, they rely on a monotonous diet centered around a single crop like rice, mainly because it is readily available and affordable.

Fortunately, recent advancements in agricultural biotechnology have made it possible to develop food crops that are nutritionally enhanced. These enhancements aim to increase the content and bioavailability of vital nutrients such as iron and vitamin A. Similar biotechnological approaches have also been employed to address chronic health issues like heart disease and cancer. In this review, we will explore some of the recent breakthroughs in agricultural biotechnology that have been implemented to improve global health outcomes.

System of Rice Intensification (SRI)

The System of Rice Intensification (SRI) is an enhanced method of rice cultivation that originated in the 1980s through on-farm research conducted in Madagascar. Father Henri de Laulanie, a Jesuit priest, collaborated closely with farmers to address the challenges of rice cultivation in acidic soils in

Madagascar. SRI was developed with the goal of reducing water consumption in irrigated rice fields. SRI involves transplanting young rice seedlings (aged 8-14 days) in a specific square pattern and maintaining the field's moisture level through periodic drying and irrigation. This approach has several advantages, including improved plant growth, reduced reliance on chemicals and fertilizers, increased land productivity, and more efficient water use, which contributes to the sustainability of the agricultural system. Unflooded fields encourage robust root development, leading to enhanced water absorption, higher grain yields, faster grain filling, and the transfer of carbon reserves from vegetative tissues to the grains.

Studies on SRI have demonstrated that maintaining paddy fields at an optimal moisture level yields better agronomic and economic results compared to continuous flooding throughout the crop cycle. Consequently, SRI now focuses on addressing the challenge of producing more rice with less water. Additionally, SRI practices can contribute to the reduction of greenhouse gas emissions and the improvement of soil health.

Direct Seeded Rice (DSR)

Transplanting, a traditional method of cultivating rice (*Oryza sativa*), has long been associated with substantial water usage and labor-intensive practices. However, several challenges, including groundwater depletion, labor shortages during peak seasons, and soil health degradation, necessitate the exploration of alternative rice planting methods that can sustain rice productivity and conserve natural resources. One such alternative gaining popularity is Direct-Seeded Rice, one of the oldest cultivation techniques. DSR is favored for its cost-effectiveness, labor-saving attributes, reduced water requirements, early crop maturity, lower production costs, improved soil conditions for subsequent crops, and reduced methane emissions. It is considered a viable option for various agricultural systems. By implementing specific agricultural practices like selecting suitable rice varieties, proper sowing techniques, optimizing seeding rates, efficient weed and water management, comparable yields to Transplanted Rice (PTR) can be achieved with DSR. Additionally, DSR may help address soil-related issues associated with rice and subsequent crops.

However, switching from PTR to DSR presents certain challenges, including weed proliferation, the emergence of weedy rice, an increase in soil-borne pathogens (such as nematodes), nutrient imbalances, poor crop establishment, pest and disease risks like blasts and brown leaf spot, among others. Despite these limitations, DSR holds promise as a technically and economically viable alternative to PTR. This article explores the potential benefits and constraints associated with the adoption of DSR.

Use of Leaf Color Chart (LCC)

The Leaf Color Map (LCC) is a cost-effective and user-friendly diagnostic tool designed for monitoring the relative greenness of rice leaves, serving as an indicator of the plant's nitrogen (N) status. The nitrogen content in rice leaves is closely linked to the photosynthetic rate and biomass production, making it a sensitive indicator of changes in the crop's nitrogen requirements throughout the growing season. Having a tool that can rapidly assess leaf nitrogen content and guide nitrogen fertilization to maintain optimal leaf nitrogen levels is crucial for achieving high rice yields through effective nitrogen management.

While chlorophyll meters offer a rapid and non-destructive method to estimate leaf nitrogen content, their high cost limits their accessibility to farmers. In contrast, the Leaf Color Map (LCC) presents an affordable and straightforward alternative. Typically, an LCC consists of a plastic strip with four or more panels, each displaying a different color gradient from yellow-green to dark green. Various types of LCCs with different color variations have been developed for rice farmers. However, this diversity has led to uncertainty about which LCC to use and the need for a standardized LCC that could serve as a reference for aligning thresholds across different LCCs. The standard LCC is five inches long, crafted from high-quality plastic, and includes four distinct colors ranging from yellow-green (No. 2) to dark green (No. 5). The color stripes on the LCC mimic the grooves found on rice leaves.

Brown Manuring

Brown manuring is a form of green manuring that adopts a 'no-till' approach by using a selective herbicide to desiccate green manure crops before they reach the flowering stage, instead of resorting to cultivation (Das *et al*., 2021). The conventional brown manuring technique involves planting green manure crops, preferably legumes, alongside the primary crop for the initial 25-30 days after sowing. After this period, a selective herbicide is applied to desiccate the green manure crops. Unlike traditional green manuring, BM does not involve incorporating the desiccated green manure crops into the soil; instead, they are left standing in the field to decompose naturally. The desiccated leaves of the green manure crops turn brown due to the herbicide application, hence the term "brown manuring."

Brown manuring offers several advantages, including eco-friendly weed management during the early stages of crop growth, as it helps suppress weed population and growth. Additionally, legume brown manure crops contribute nitrogen to the main crop through biological nitrogen fixation, reducing the need for nitrogenous fertilizers. This practice also increases the organic carbon content of the soil, leading to improved soil physicochemical and biological properties. Brown manuring can further conserve soil moisture, reduce runoff, and mitigate wind erosion. The enhanced soil fertility, reduced weed competition, and other benefits associated with brown manuring ultimately result in higher crop productivity and economic gains for farmers.

Enhancing Resource Use Efficiency

The effectiveness of food production hinges significantly on the management of various resources. Resource utilization efficiency is a pivotal factor in agriculture, as it profoundly influences farm production and income. Within agriculture, essential inputs such as manures, fertilizers, irrigation systems, labor (both human and animal), seeds, working capital, farm machinery, and crop protection measures are of paramount importance. The level of farm income is intricately tied to how efficiently farmers are able to harness these resources. Farmers' ability to maximize their income and savings is contingent on their proficiency in using these limited resources effectively. In essence, higher efficiency in resource utilization empowers farmers to enhance their income and accumulate savings.

Site-specific Nutrient Management

Site-Specific Nutrient Management (SSNM) is an approach aimed at supplying plants with nutrients in a manner that aligns closely with their natural and specific spatial and temporal nutrient requirements. This method utilizes various SSNM tools, including remote sensing, GPS, GIS systems, Variable Rate Technology (VRT), and crop tracking. In the context of horticulture and garden plants, insufficient fertilization can lead to crop losses, while excessive fertilization can pose environmental risks. The introduction of SSNM has made it feasible to account for soil nutrient variations across fields and prescribe fertilizers accordingly.

Another vital area where SSNM can benefit farmers in India is in stress management. Many cultivated soils in India are acidic, with significant regional variations in pH levels. SSNM can assist in identifying nutrient stress through remote sensing and integrating this data into a geographic information system. This approach enables the precise application of fertilizers and soil amendments tailored to the specific needs of each site, enhancing fertilizer use efficiency and reducing nutrient losses. Although SSNM in India is still in its early stages, there are promising opportunities for its adoption, particularly in high-value crops. Successful implementation will require effective collaboration between the public and private sectors, as well as farmers, to embrace and implement these innovative strategies for productive outcomes.

Fertigation

Fertigation is a farming practice that involves the application of fertilizers or nutrients directly into a farming system through the irrigation network. In this method, the nutrient inputs are dissolved in water and are absorbed directly by plants when they take up water. The term "fertigation" is a combination of "fertilizer" and "irrigation," and while it has been used for centuries, it has evolved significantly over time.

Fertigation can be employed alongside various irrigation methods, including sprinkler, drip, and soaker irrigation systems. Among these, drip irrigation is the most compatible and beneficial for fertigation. Compared to traditional methods like band or broadcast application of fertilizers, fertigation is considered more precise and controlled. It typically involves the use of lower volumes of fertilizer compared to other techniques. Fertigation is commonly used in hydroponic or soil-less growing systems, where it provides a straightforward means of delivering precise nutrient doses tailored to the specific needs of plants in these systems. Phosphorus, potassium, and nitrogen are among the most commonly used compounds in fertigation systems due to their critical roles in the growth and development of many crop species.

Fertigation offers several advantages over traditional broadcast and band fertilization methods:

a) It maintains a consistent nutrient supply, reducing fluctuations in nutrient concentration in the soil.
b) Nutrients are efficiently utilized and accurately applied based on the crop's nutritional requirements.
c) Fertilizers are evenly distributed throughout the irrigated soil volume.
d) Nutrients can be applied to the soil even when soil or crop conditions would otherwise prevent conventional equipment from entering the field.

Real Time Nutrient Management

Nitrogen (N) is a crucial nutrient for achieving high yields in modern rice crops. In many regions around the world, including the Indo-Gangetic plain of northwestern India, farmers tend to apply excessive amounts of N fertilizers in their quest to boost rice growth and profitability. This practice has led to a notable reduction in the efficiency of nitrogen fixation, often not exceeding 50% (as observed in studies by Katyal *et al*., 1985 and Bijay-singh *et al*., 2001). In the case of rice cultivation in Punjab, it is recommended to apply 120 kg of N per hectare in three equal splits—during planting, 21 days after planting (DAT), and 42 DAT. However, these timing and dosage recommendations may not always align perfectly with the rice plant's actual nutrient demand patterns. Consequently, nitrogen losses occur through processes such as NH_3 volatilization, NO_3 leaching, nitrification, and denitrification. This results in reduced fertilizer N application efficiency (as highlighted by Aulakh and Bijay-Singh, 1997).

The current practice of recommending 120 kg of N/ha for rice is based on soil test plant response functions and does not adequately account for factors that can limit yields, such as changing weather conditions and crop dynamics. Stalin *et al.* (1996) also found that soil test-based N fertilizer recommendations were not suitable for achieving higher yields in flooded rice fields. Recent research has indicated that an adequate supply of nitrogen is required after panicle initiation (typically after 42 days) to extend the duration of photosynthetic activity and fulfill the nitrogen needs during the grain-filling stage (as shown by Peng *et al*., 1996). Additionally, Peng and Cassman (1998) demonstrated that recovery efficiency could be significantly improved (by 78%) by applying urea during panicle initiation. Therefore, to achieve higher yields and enhance nitrogen use efficiency, it is essential to manage fertilizer N more effectively by adjusting its application to align with the actual requirements of the rice plants, particularly during critical growth stages.

Bio-intensive Farming

Bio-intensive agriculture is an organic farming approach designed to achieve maximum crop yields from minimal land area while concurrently enhancing biodiversity and preserving soil fertility. The primary objective of this method is to establish long-term sustainability within a closed agricultural system. Bio-intensive agriculture is especially well-suited for small-scale farmers, backyard gardeners, and is also applicable to small commercial farms, particularly in developing countries. In the bio-intensive farming system, all key components must work together synergistically to achieve optimal results. These essential components include:

a) Double-dug beds with soil that is thoroughly aerated and loosened.
b) Utilization of compost to promote soil health and vitality.
c) Close plant spacing to protect soil microorganisms, reduce water loss, and maximize crop yields.
d) Companion planting to optimize the utilization of nutrients, sunlight, and water resources.
e) The production of both food calories for the farmer and carbon for the soil.
f) The use of open-pollinated seeds to safeguard genetic diversity and enable gardeners to develop their own adapted varieties.

Bio-intensive farming practices can lead to remarkable resource savings compared to commercial agriculture, such as a 67% to 88% reduction in water usage, a 50% to 100% reduction in fertilizer usage, and a 99% decrease in energy consumption. Moreover, when these techniques are correctly implemented, they can yield 2 to 6 times more food production and accelerate soil building up to 60 times faster than natural processes. Additionally, bio-intensive agriculture can significantly reduce the amount of land required for cultivation, often by half or more.

Promoting low or no cost inputs

Urea Deep Placement (UDP)

Urea Deep Placement (UDP) is a proven and straightforward technique designed and validated by the International Fertilizer Development Center. It is an effective soil nutrient management approach, particularly well-suited for smallholder farming systems. By employing UDP, rice growers consistently achieve yield increases of 15-20% while using significantly less fertilizer, about one-third less. UDP technology involves precisely placing relatively large urea pellets (typically weighing 1-3 grams) approximately 7-10 cm below the soil surface, near the root zone of the rice plant. Unlike surface-applied granular or granular urea, which requires multiple applications during a crop season, UDP utilizes urea briquettes that are applied just once per growing season. This technology ensures a steady supply of nitrogen to the crop throughout its growth cycle. One of the key benefits of UDP is that it enables plants to absorb a higher proportion of the applied nutrients, leading to increased yields and reduced production costs for farmers. In the context of submerged or flooded soils, the depth at which UDP is placed plays a crucial role in influencing nitrogen transport and the transformations that occur within the UDP system. It's worth noting that the physical, chemical, and microbiological properties of submerged rice soil at the placement depth are intricate, diverse, and dynamic. The soil-to-water ratio within a field can vary significantly due to fluctuations in the water table's depth and duration over the swampy terrain.

SPAD-502 meter

The SPAD-502 meter is a portable device widely utilized for swift, precise, and non-destructive measurement of chlorophyll levels in leaves. It has found extensive application in both research and agricultural contexts across various plant species. Manufactured by Spectrum Technologies in Plainfield, Illinois, USA, the SPAD-502 offers a straight forward and rapid means to assess chlorophyll content in leaves. This meter relies on two transmittance values: the transmittance of red light at 650 nm, which chlorophyll absorbs, and the transmittance of infrared light at 940 nm, which chlorophyll does not absorb. While the use of SPAD meters to estimate leaf chlorophyll content has become increasingly prevalent, the challenge lies in accurately calibrating SPAD readings into direct units of chlorophyll content. Understanding the relationship between these two parameters is crucial. Numerous studies have investigated the correlation between SPAD readings and chlorophyll content per leaf in different plant species. However, it's noteworthy that this relationship can vary significantly, sometimes even within the same species. This variability is attributed to differences in measurement conditions and leaf structures, which affect light reflection and scattering. Consequently, there is still a need to clarify the connection between SPAD readings and leaf-specific chlorophyll content.

Green Seeker

The Green Seeker portable crop sensor is a cost-effective and user-friendly measurement tool designed for evaluating the condition and vitality of crops. By providing objective readings via this handheld device, farmers can make informed decisions regarding the appropriate fertilizer application for their plants. This approach enhances fertilizer utilization, benefiting both the farmer's income and the environment. The sensor operates based on the NDVI (Normalized Difference Vegetation Index) principle and presents NDVI values ranging from 0.00 to 0.99.

Conclusion

The challenge of persistently low and fluctuating incomes among farmers is a significant concern in India, affecting nearly half of the country's population who rely on agriculture for their livelihoods. This issue has given rise to agrarian distress and poses threats to the future sustainability of agriculture. To secure the well-being of millions of farming households and ensure the future of the agricultural sector, addressing the problem of low farmers' income is of utmost importance. Addressing this issue has broader implications beyond agriculture; it can help bridge the income gap between the agricultural and non-agricultural sectors, alleviate agrarian distress, promote inclusive economic growth, and inject vitality into the agriculture sector. A more attractive income in farming can also draw the youth towards agriculture as a profession and reduce the pressure on non-farm employment opportunities, which are not expanding as anticipated.

Several challenges contribute to the problem, including the shrinking size of land holdings, with approximately 85% of farmers classified as small and marginal landholders. Additionally, around 60% of cultivation relies on rainfed agriculture, leaving it vulnerable to monsoon fluctuations. Soil degradation, yield stagnation in most crops, nutrient deficiencies, low overall productivity, the impact of climate change, limited resources available to many farmers, and significant food losses throughout the supply chain compound these challenges. The slower growth rate in the agriculture sector raises concerns about future food and nutritional security. The ambitious but essential goal of doubling farmers' income by 2022 can be achieved through various strategies. These include reducing cultivation costs, increasing crop productivity, implementing efficient rainwater management, adopting conservation agriculture and resource conservation technologies, practicing sustainable agricultural management, diversifying agricultural activities, embracing integrated farming systems and integrated crop management, effectively managing crop residues, and ensuring that farmers receive fair prices for their produce. These measures collectively aim to uplift the livelihoods of farmers and revitalize the agriculture sector, fostering long-term sustainability and economic well-being.

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