Pakistan Agricultural Research Council
Islamabad

Climate-Smart Agriculture Technologies and Practices in Pakistan

Consortium for Scaling-up Climate Smart Agriculture in South Asia (C-SUCSeS) Project
(IFAD Grant No. 2000001968)

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SAARC Agriculture Centre
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IFPRI

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SAARC Agriculture Centre (SAC)

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Inventory of Climate-Smart Agriculture (CSA) Technologies and Practices in Pakistan was conducted as one of the activities under the project Consortium for Scaling up Climate-Smart Agriculture in South Asia (C-SUCSeS) of SAARC Agriculture Centre in 2022.

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This book 'Climate-Smart Agriculture Technologies and Practices in Pakistan' contains the climate-smart agriculture (CSA) technologies and practices of Pakistan produced as an output of the inventory of CSA technologies conducted by the National Focal Point of C-SUCSeS project of Pakistan and the associates working under the Pakistan Agricultural Research Council (PARC). The CSA technologies and practices in this publication are those of the authors gathered from various sources and do not imply any opinion whatsoever on the part of SAC.

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Foreword

Agriculture is the backbone of Pakistan's economy. More than 65-70% of the population is involved in farming, either directly or indirectly, through the production, processing, and distribution of major agricultural commodities. It contributes approximately 24% of GDP, employs half of the labor force, and is the largest source of foreign exchange earnings. It feeds the entire rural and urban population. The agriculture sector is the major contributor to the overall export earnings of Pakistan. Agriculture is equally important for industrial development. Out of about 5000 industrial establishments in Pakistan, about 60 percent are agro-based. The entire globe is dealing with the effects of climate change, particularly in South Asian countries. Pakistan is one of them, affected by climate change in the form of floods, heat waves, and other environmental disasters. The time has come to adopt new technologies in order to reduce environmental risks, use crop varieties that are more tolerant of climate change, and modify cropping systems, crop rotations, tillage techniques, and other planting techniques in order to maximize crop production in the face of changing climatic conditions. In order to maintain a continuous supply of fundamental food goods at reasonable costs throughout the nation, the government is regularly monitoring major crops and developing policies and planning initiatives. The government's main objective is to increase financial inclusion in the agricultural sector in order to increase productivity and exports and enable economic growth that is driven by rural development. It is now necessary to adapt to climate smart agriculture (CSA), which has a lot of potential as a means of achieving agricultural sustainability by conserving, enhancing, and using natural resources more effectively. This can be achieved by carefully combining the management of the existing natural and biological resources with outside inputs. But in order to achieve this goal, training for farmers and other stake holders is very essential.

Dr. Ghulam Muhammad Ali
Chairman, PARC
Islamabad, Pakistan

Pakistan Agricultural Research Council

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Preface

This book has been written with the financial support of SAARC Agriculture Centre (SAC), through its C-SUCSeS project and 34 different climate-friendly, resource conservation technologies have been mentioned in detail. These technologies are soil health and environmentally friendly and in addition to it are economically supportive to the farming community. I hope this book will be helpful in the vital promotion and adoption of climate-friendly technologies among the smallholder farmers of Pakistan as well as among the farmers of SAARC Member States. Climate smart agriculture (CSA) is an approach, which seeks to improve agricultural productivity and resilience to climate change, while simultaneously reducing agricultural greenhouse gas emissions and enhancing carbon sequestration. It does this by combining traditional agricultural practices with modern technology and agricultural science. CSA helps farmers make informed decisions about how to use their land and resources to maximize their yields and reduce their impact on the environment. By adapting to the changing climate, farmers can increase their resilience to its impacts and ensure that their livelihoods remain sustainable in the long term. Climate smart agriculture is becoming increasingly important in today's world. With the ongoing effects of climate change, traditional agricultural practices may no longer be sufficient to ensure food security and sustainability. Climate smart agriculture aims to address these challenges by implementing innovative and adaptive strategies that both mitigate and adapt to climate change.

I hope this book will be helpful in the vital promotion and adaption of climate-friendly technologies among the smallholder farmers of Pakistan as well as among the farmers of SAARC Member States. I would like to avail this opportunity to express my sincere appreciation to all the authors for their hard work. I am thankful to C-SUCSeS project, SAARC Agriculture Centre (SAC) for its generous financial support for the writing of this book. I am confident that this work will pave the way for further research, development, and promotion of climate smart agriculture in South Asia.

Dr. Imtiaz Hussain
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Acknowledgement

The main aim of Consortium for Scaling-up Climate Smart Agriculture in South Asia (C-SUCSeS) project is to identify and scale-up of climate smart technologies in the SAARC Member States. In Pakistan under this project different climate smart technologies are being demonstrated on the farmers' fields in the rainfed area of Potohar and similarly in the rice-wheat area of Punjab.

CSA inventory will be helpful in promotion of these technologies in the different ecologies of Pakistan. Experiences gained from this project will also be helpful in the promoting of these technologies on large scale in the SAARC region and will be helpful in upgrading economy of the farmers and will have also positive effects on soil health and environment of the whole region.

I am extremely grateful to Dr. Ghulam Muhammad Ali, Chairman PARC for his support and guidance for the implementation of project. I am also thankful to Dr Muhammad Asim Principal Scientific Officer / P.I of the project, Dr Sikander Khan Tanveer Principal Scientific Officer / Programme Leader Wheat Program NARC / National Coordinator Wheat PARC, Mr Syed Haider Abbass, Senior Scientific Officer Wheat Programme NARC and similarly Dr Shehbaz Hussain, Principal Scientific Officer/ Programme Leader Rice Programme, Kala Shah Kaku and all other teams members for the implementation of this project on the farmers' fields.

Thanks to all officers and staff of Agriculture Extension Department who have helped in the implementation of the project. I am also grateful to farmers who have tested and demonstrated these technologies on their farms, which will be helpful ultimately in the dissemination of these technologies on a large scale. I am also grateful to Dr. Md. Baktear Hossain, Director, SAARC Agriculture Centre (SAC), Dhaka for his continuous support in the implementation of the project in SAARC Member States. I express my appreciation to Mr. Kinzang Gyeltshen, Regional Programme Coordinator for his day and night hard work for the implementation of the project. I would like to acknowledge the guidance and financial support from the SAARC Agriculture Centre (SAC), International Food Policy Research Institute (IFPRI), International Fund for Agricultural Development (IFAD), and SAARC Development Fund (SDF) in the implementation of the programme.

Dr. Imtiaz Hussain

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Acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asian Development Bank
AIP	Accelerated Implementation Programme
ARI	Agricultural Research Institute
AWD	Alternate Wetting and Drying
BCR	Benefit Cost Ratio
BGA	Blue Green Algae
BT	Bacillus Thuringiensis
CA	Conservation Agriculture
CF	Continuous Flooding
CIMMYT	International Maize and Wheat Improvement Center
CP	Chisel Plow
CSA	Climate Smart Agriculture
CSIs	Chitin Synthesis Inhibitors
CT	Conventional Tillage
Cu	Copper
DAMs	Differentially Accumulated Metabolites
DAS	Days after Seeding
DSR	Direct Seeding of Rice
FCR	Feed Conversion Ratio
FFS	Farmer Field School
FIRB	Furrow Irrigated Raised Bed
FYM	Farm Yard Manure
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GM	Genetically Modified
HPR	Host Plant Resistance
ICARDA	International Centre for Agricultural Research in the Dry Areas
IPM	Integrated Pest Management
IRRI	International Rice Research Institute

JHAs	Juvenile Hormone Analogues
K	Potash
LCC	Leaf Color Chart
LER	Land Equivalent Ratio
LF	Leaf Folder
MMRI	Maize and Millets Research Institute
Mn	Manganese
MRR	Marginal Rate of Return
MRTN	Maximum Return to Nitrogen
MT	Minimum Tillage
MTR	Mechanical Transplanting of Rice
N	Nitrogen
NARC	National Agricultural Research Centre
NFDC	National Fertilizers Development Centre
NUE	Nitrogen Use Efficiency
OPVs	Open Pollinated Varieties
P	Phosphorus
PARC	Pakistan Agricultural Research Council
PIPs	Plant Incorporated Protectants
PRB	Permanent Raised Bed
PV	Photovoltaic
SARE	Sustainable Agricultural Research and Extension
SOM	Soil Organic Matter
SPAD	Soil Plant Analysis Development
SPIS	Solar Power Irrigation System
SRI	System Rice Intensification
WUE	Water Use Efficiency
Zn	Zinc
ZT	Zero Tillage

1. Introduction

1.1 Overview of Agricultural Scenario in Pakistan

Pakistan has a total area of 79.90 million hectares, with 234 million people and 24.10 million hectares of arable land. It has a long latitudinal extent stretching from the Arabian Sea in the south to the Himalayan Mountains in the north. It is located in the sub-tropics and partially in the temperate region. Climatically most of the parts of Pakistan are arid to semi-arid with significant spatial and temporal variability in climatic parameters. About 95% of the annual rainfall occurs due to monsoon rains; a dominant hydro-meteorological resource for Pakistan. The Greater Himalayan region above 34^0N receives winter precipitation mostly in the form of snow and ice. The snowmelt contribution keeps the rivers perennial throughout the year. The Arabian Sea in the south provides about nine hundred ninety kilometers of coastline. The coastal climate is confined to a narrow strip along the coast in the south and southeast. The north is dominated by the mountain climate ranging from humid to arid. In between, the climate is broadly of tropical continental nature.

Pakistan is basically an agricultural country and sustainable growth of the agriculture sector is vital for its food security and development. The country has about a century-old largest man-made canal system in the world. Agriculture is the major contributor to the employment and foreign exchange earnings. It also provides industrial raw materials, its share in GDP is 22.9% and it provides employment to around 37.4% of the labor force. During 2022-23, the contribution of important crops was recorded at 18.23% to value addition in the agriculture sector and 4.18% to GDP. Other crops contributed 14.49% in value addition to the agriculture sector and 3.32% to GDP. The share of livestock in agriculture is 62.68% and 14.04% of GDP. Animal husbandry is the most significant activity of the dwellers of rural areas of Pakistan. Poultry sector is one of the most important segments of livestock that provides employment to more than 1.5 million people in the country. The share of the fishing sector is 1.39% in agriculture value addition and 0.32% to GDP. The forestry sector has a share of 2.14% in agriculture value addition and 0.49% in GDP.

During the last crop season total fertilizer offtake was 3,826,000 tonnes, which also includes 586,000 tonnes imported fertilizer. The maximum fertilizer offtake is 2,861,000 tonnes nitrogen, 903,000 tonnes phosphorus and 63,000 tonnes potash. Import of insecticides was 24,151 tonnes having value of 23,296 million rupees. Area irrigated by different sources is 18.86 million hectares which includes different sources including canals, wells, canal wells, tube wells and others. Water availability with the passage of time is decreasing in the country (Pakistan Economic Survey 2022-23).

The country is facing different environmental issues like unavailability of rains in the rainfed ecologies, less availability or even unavailability of water in the canals at the critical crop growth stages, continuous reduction in soil organic matter due to improper soil management, over pumping of underground water for agriculture purposes, residue management in the rice-wheat cropping system, less use of certified seed of recommended varieties of different crops and very less use of integrated nutrients and crop rotations for better crops production. In addition to these factors due to the sky rocketing prices of inputs, fuel and electricity, it is becoming very difficult for the farming community to continue agriculture by adapting the conventional agricultural practices.

Table 1. Area and production of different crops during 2022-23

Sl. No.	Crop	Area (000 ha)	Production (000 tones)
01	Wheat	9,043	27,634
02	Rice	2,976	7,322
03	Cotton	2,144	4,910 (bales)
04	Maize	1,720	10,183
05	Sugarcane	1,319	91,111
06	Gram	830	238
07	Rape seed & mustard	509	796
08	Potato	341	8,319
09	Bajra	241	256
10	Moong	218	135
11	Canola	200	130
12	Sunflower	179	124
13	Onion	128	1,684
14	Jowar	59	49
15	Tobacco	43.7	133.7
16	Barley	36.1	37
17	Chili	31	82
18	Blackgram	7.0	4.2
19	Lentil	6.5	3.8

Source: Pakistan Economic Survey 2022-23

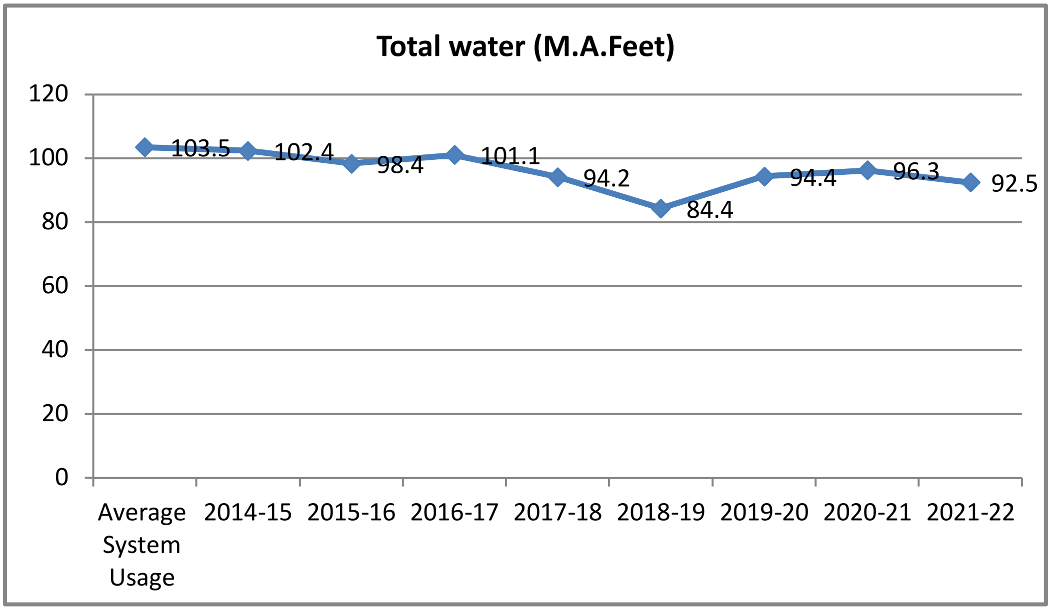

Fig. 1 Water availability in Pakistan during 2014-15 to 2021-22

Source: Pakistan Economic Survey 2022-23

2. Purpose of CSA Inventory

The purpose of the Climate Smart Agriculture (CSA) inventory is to present briefly the information on different CSA technologies and practices that are either released or under active research in different fields at different locations. From the inventory, the best CSA technologies and practices for smallholder farmers will be identified. The promising technologies will be scaled up through national policies and programs. The inventory report can be used by national and international donors, policymakers, researchers, extension personnel, NGOs, and other stakeholders for better investment decisions and priority setting regarding the scaling-up of CSA technologies. Thus, the main purpose of the CSA inventory is to integrate climate change adaptation and mitigation strategies with the goal of ensuring food, nutrition, and livelihood security.

3. Methodology of CSA Inventory

The CSA technologies have been collected from both secondary and primary sources of information. Secondary sources include a review of published literature, reports, workshop/seminar proceedings, journals, leaflets, bulletins, etc. Primary sources of the collection were from the meetings, workshops, and seminars where researchers, extension personnel, academicians, and other relevant stakeholders participated. The identified technologies are either released by a research organization or on trials at farmers' fields. A draft inventory of CSA technologies was prepared and then it was discussed and finalized by experts in the consultation meetings. The inventory of CSA technologies was conducted with the aim of gathering CSA technologies and prioritizing viable and women-friendly technologies to scale up through national policies and programs in the country.

4. Concept and Pillars of CSA

According to FAO (2010), Climate Smart Agriculture (CSA) is an approach to sustainably increase agricultural productivity, build resilience to climate change, and reduce or remove greenhouse gas emissions. The concept of CSA in Pakistan reflects an approach to improving the integration of agricultural development and climate responsiveness. It aims to achieve food security as well as broader development goals in the face of a changing climate and rising food demand. Its objective is to achieve more efficient, effective, and equitable food systems that address environmental, social, and economic challenges across productive landscapes.

CSA stands on the three pillars:

- Sustainably increase agricultural productivity and income;
- Make farms more resilient and adapt to climate change;
- Reduce and/or remove greenhouse gas emissions.

5. Brief Description of Individual Technology

5.1 Laser Land Leveling (LLL)

Introduction

Laser Land Leveler (LLL) is a modern agricultural instrument that is specially designed for precise field leveling. It is a more comprehensive and dependable method of making flat fields for planting than visual assessment or land surveying. It is one of the most essential irrigation technologies accessible to Pakistani farmers. The laser land leveler (LLL) contains a laser (transmitter) that generates a fast-rotating beam by a sensor (receiving unit) mounted on a tractor and directed towards the scraper unit parallel to the necessary field plane, which is detected.

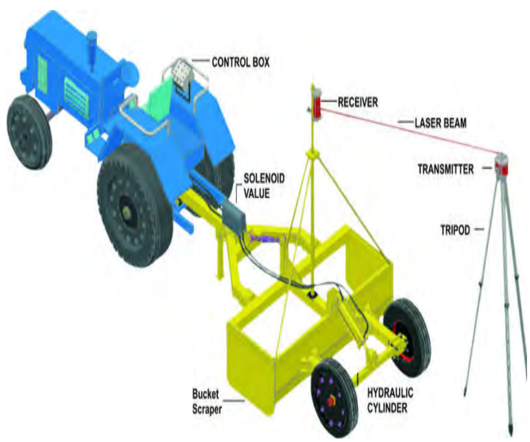

Fig. 2 Laser land leveling mechanism

A hydraulic control system automatically adjusts the scraper level based on the received signal. The scraper guiding is very automatic, removing the possibility of man-made mistakes and enabling consistently exact field leveling. There are two units in the configuration. The laser transmitter is positioned on a high platform that rapidly spins and sends the laser light in a circle, similar to a lighthouse, except that the light is a laser and so remains in a very narrow beam.

Benefits of the technology

- Water smart technology.
- Saving up to 35% irrigation water.

- Reduced weed infestation.
- Increased cultivable area by about 30%.
- Improved productivity by up to 50%.
- Decreased farm operation time by 10%.

Limitations of the technology

- The equipment/laser instrument and maintenance costs are quite expensive.
- Skilled operator is required to set/adjust laser settings and drive the tractor.
- Unsuitable for rough and undulating terrain.

Focus areas of LLL technology

Water conservation: In most areas of Pakistan, irrigation is needed to grow a crop. So, water conservation in the agriculture sector is the top priority due to the dwindling availability of water. By improving irrigation efficiency to ensure uniform ground coverage without waterlogging or runoff, laser land leveling can play a good role.

Uniform plant growth: When irrigation systems can distribute water uniformly to all plants, there is fewer early plant death due to excess or under-watering, resulting in better, and more consistent growth. All crops mature at the same time, resulting in higher yields.

Energy, time, and cost-saving: Laser land leveling is a more efficient field leveling process that requires less labor hours to execute. It is a cost-effective way of field preparation as it yields more while requiring less energy to monitor and regulate farm irrigation systems.

Eco-friendly: Laser land leveling requires less emission-producing farm equipment than traditional methods, less water-pumping equipment, and speeds up and simplifies field maintenance and harvesting. It significantly minimizes water waste and protects soil and river water by reducing fertilizer and chemical runoff.

Adaptability rate

- In Pakistan, LLL was introduced in the irrigated systems of Punjab and has been promoted by the Department of On-farm Water Management throughout Pakistan. LLL implies a capital investment in the needed LLL implements and a skilled worker to manage the laser settings and run the tractor. Both imported and locally manufactured laser land leveling units are available in the market.
- The agriculture industry remains important to the economy, and local agricultural cooperative societies play an important role in providing farmers with access to laser leveling.
- These cooperatives, which were mostly created in the previous decade, provide farmers with a variety of services such as equipment rental, seed and fertilizer sales, and short-term loans. In the previous six years, the Punjab province had pushed them to acquire laser levelers, which are subsequently made available for rental by farmers, by providing a 30% rebate on the purchase price. Other provinces are also encouraging the use of Laser land levelers.

- Now, approximately 2000 laser land levelers are in use in Punjab, the majority of which are owned by cooperatives. Despite its benefits and widespread availability, this technology's adoption remains relatively low, and earlier estimates show that just one-seventh of cultivable lands in Punjab have been laser-leveled.
- The total LLL unit requirement for land leveling is around 32,734, however, there are around 15,000 LLL units in the field. There are around 13,000 LLL units in the Punjab province: about 10,000 provided through government (subsidy) schemes and 3,000 procured by farmers privately/commercially. The majority of the LLL units are operated by service providers who provide LLL services to farmers on a rental basis throughout the Punjab province – making the technology more accessible by making the lumpy technology divisible and providing the needed operational skills, although potential economies of scale may generate bias in favor of leveling larger plots (Ali et al., 2018). In other provinces (Sind, Khyber Pakhtunkhwa and Baluchistan) there are only around 2,000 units working, however, the government is focusing on the provision of LLL units to farmers all over Pakistan so that most of the areas can be leveled.

Suitability to smallholder farmers

Local agricultural cooperative societies play an important role in providing farmers with access to laser leveling through sanctioning short-term loans on minimum interest and also reduction of purchase price. As in Punjab, a farmer can purchase a land leveler on a 30% rebate. Furthermore, a farmer can use LLL as a rental. Thus, the technology is suitable for use by smallholder farmers and commercial farmers.

Success story of the technology

The laser-land leveling helps farmers save water, boost water use efficiency (WUE), increase crop yields, and enhance net income. In a cropping year, level fields saved an average of 51% more water than unleveled fields. The yields of rice, wheat, and maize (fodder) from leveled fields are 6-10% higher than those from unleveled fields. The WUE of rice, wheat, and maize (fodder) on level fields is 33-38 % higher than in unleveled fields. The net annual income from level fields is 32% more than that from unleveled fields. It is also feasible to apply a little depth of water to level fields.

The expense of laser-land leveling is repaid within a season. The level fields require laser leveling again every three years for improved water applications. Laser land leveling (LLL) has no systematic pattern or substantial influence on soil salinity or fertility. In level fields, a little depth of water can be applied, which is not possible in unleveled fields.

A lot of benefits of using this technology in the rice-wheat areas have been mentioned by Jat et al., (2006). Laser land leveling (LLL) has pushed water, cost-saving, and yield-increasing techniques in South Asia's Indo-Gangetic plains irrigated rice-wheat systems. Empirical findings from a survey of 350 farmers from four major rice-wheat growing areas in Punjab, confirm favorable outcomes in terms of water savings, wheat and rice yields, and as well as in household income of surveyed farms. The findings suggested that Laser land leveling (LLL) adoption is not only economically farmer-friendly, but it is also soil health and environment-friendly.

Fig. 3. Laser land leveling in the field

Challenges for scaling up the technology

The high cost of equipment and undulating land are the great challenges for scaling up of this technology. Thus, the popularization of this technology among the farmers in a participatory manner on a large scale requires adequately directed attention on a priority basis with necessary strategies and financial support from the government.

5.2 Solar Powered Drip Irrigation System

Introduction

Solar-powered high efficiency irrigation system (SPHEIS) allows the use of solar energy for water pumping, replacing fossil fuels as a source of energy and lowering greenhouse gas emissions as compared to traditional irrigated agriculture. It is a major impacting source of technology for water management resources, especially for drip irrigation system.

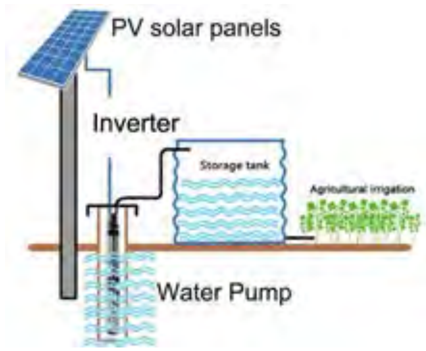

Fig. 4 Mechanism of pumping out and water use by solar system

The operation of a (SPIS) is straightforward. A solar generator powers an electric motor pump, which pumps water directly into an irrigation system or into an elevated reservoir. Drip irrigation reduces water loss due to evaporation, runoff, and infiltration by providing water via a piping network to drip emitters, which discharges the water directly at the base of the crops. Drip irrigation uses 20-60% less water than regular flood irrigation.

When the sun shines on a solar panel, the PV cells in the panel collect solar energy. As a result of the electrical charges that are created by this energy, which move in response to an internal electrical field within the cell, electricity begins to flow. Resource efficiency, maximum reliability, and minimal maintenance are essential design goals for SPHEIS. One distinctive quality of SPHEIS is that typically no battery backup is needed as batteries are expensive, labor-intensive to maintain, and frequently need to be replaced.

Benefits of the technology

- It is an energy as well as water smart technology.
- It is the best alternative in areas where there is no electric grid station.
- Saves 20-60% water as compared to flood irrigation.
- Potential to minimize greenhouse gas (GHG) emissions
- Enable crop production in agricultural areas with low rainfall.
- No battery backup is needed.

Some focus areas of SPIS technology are as follows:

- A solar-powered irrigation system's total setup should be optimized for the lowest lifetime cost while taking into account how its linked modules are connected.
- Redesigning pressure-compensating drip emitters to reduce the necessary system pressure, this pressure reduction permits the use of less expensive pumps and power systems.
- Investigating ways to further reduce system costs, energy consumption, and water use using pump design, pump controls, and irrigation scheduling.
- In order to comprehend the irrigation requirements and limitations of our target customers, we must conduct stakeholder interviews all over Pakistan.

Limitations of solar photovoltaic (PV) technology

- Solar photovoltaic or solar cells are highly sunlight-dependent.
- This system only works during daytime under the good sunlight.
- The performance of a solar cell is affected by temperature as well as the spectrum and intensity of incident sunlight.

Adaptability rate

The government of Pakistan is encouraging the large-scale adoption of solar energy in the agriculture sector. The government of Punjab, Pakistan is providing an 80% subsidy on the installation of HIES coupled with a solar system. The government of Khyber Pakhtunkhwa has also initiated a 50%-subsidy scheme on SIPs in rainfed and water-scarce areas. The Sindh government has launched several solar-powered tube well schemes to strengthen the agriculture sector.

Suitability to smallholder farmers

The Pakistan Agricultural Research Council (PARC) plans to make solar-powered, off-grid drip systems an accessible option for small and medium-scale farmers by lowering pumping power and capital expenses. Thus, the technology is both technically and financially sound. Effort is needed to further reduce system costs, energy consumption, and water use using pump design, pump controls, and irrigation scheduling. This brings attention to the researchers and policymakers. Thus, all these steps endorse the high suitability of this technology for smallholder farmers.

Success story of the technology

The studies show that SPIS in Pakistan is becoming a cost-effective and sustainable option for irrigation, particularly in remote and off-grid areas. It is estimated that solar irrigation can provide irrigation water to about 1.5 million hectares of land in Pakistan (Shah et al., 2021). In Pakistan, solar energy is abundant, with an average annual solar radiation of 5.5 to 6.5 kWh/ m^2/day. Solar irrigation has significant potential for the improvement of agricultural productivity and it can provide a reliable and sustainable source of irrigation water for farmers particularly in remote and off-grid areas (Tariq et al., 2021). This would not only help reduce the consumption of fossil fuels and associated environmental impacts but also increase farmer's income and reduce their operational cost (Hussain et al., 2023).

The Pakistan Agricultural Research Council (PARC) in the Potohar region pioneered a new model for sustainable Mini-Dam development, the Solar-powered Irrigation System (SPIS) based on the implementation of a Solar-powered Pumping System (SPPS). Its integration is with high-efficiency irrigation technologies, such as drip-basin irrigation. The new irrigation mechanism was implemented on a large scale of about 20 acres, with the goal of demonstrating a series of integrated agricultural practices unified by a sustainable system, such as agroforestry, pisciculture, seasonal vegetable cultivation, tunnel farming, and orchard arboriculture. In addition to increasing the region's productive yield, the SPIS had low operational expenses due to its renewable-energy design, minimizing environmental effects while increasing land fertility.

Fig. 5. Field irrigation by using the solar water pumping system

Challenges for scaling up the technology

The country is facing water scarcity and high operational costs for traditional irrigation systems, hindering agricultural productivity. Solar-powered irrigation system (SPIS) can potentially provide a sustainable and affordable solution, nevertheless, it faces technical, financial, and policy barriers to adoption. The government should undertake effective strategies to scale up solar system technologies like Solar-powered high-efficiency irrigation systems (SPHEIS) so as to save water and energy resources. Solar cells are highly sunlight dependent, so this system only works in the daytime, not at night and its efficiency is very low in the monsoon season when the sky remains cloudy.

5.3 Direct Seeding of Rice (DSR)

Introduction

Direct seeding of rice involves sowing and sprouting rice seed directly into the field, eliminating the time-consuming process of hand-planting seedlings and significantly lowering the crop's water requirements.

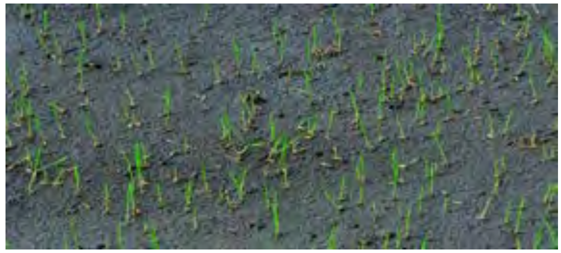

Fig. 6 Germination of direct seeded rice.

The scientists of Pakistan Agricultural Research Council (PARC) initiated research work on DSR in the early 1980s with the support of IRRI on a small-plot field experimentation at the National Agricultural Research Centre (NARC), Islamabad. The scientists tested and established DSR technology through on-station and on-farm trials at different research stations and farmers' fields in the province of Punjab. In the early days, major problems in the upscaling of DSR were the availability of precise DSR drills and post-emergence herbicides for control of complex weed flora. Introduction of Bispyribac-sodium in 2003, a broad-spectrum post-emergence herbicide, provided effective control of weeds in DSR without any Phyto-toxicity on rice giving impetus to DSR adoption.

In Pakistan, rice is traditionally grown through manual transplanting of 25 - 35 days old seedlings in a well-prepared, puddled, and flooded field, which consumes over 20% of the available water resources in the country. This method of rice cultivation system is not resource-efficient. Direct seeding of rice (DSR) is one of the good options for saving water and labor costs in the cultivation of rice.

Methods for direct seeding of rice

Dry direct seeding:

- Sow rice seeds onto the dry soil surface.
- Then integrate the seed by ploughing or harrowing.

Broadcasting:

- Spread 35- 40 kg of seeds uniformly in 1 hectare of land by hand in furrows.
- Pass a furrower along the prepared field to make shallow furrows.
- Cover the seeds with a spike-tooth harrow after disseminating.

Seed drilling:

- To drill seeds, precision equipment such as the Multicrop DSR planter was evaluated and locally manufactured under CIMMYT-USAID Agricultural Innovation Program in Pakistan.
- Drill 30-35 kg of seeds per hectare.
- The machine places seeds in both dry and moist soils and then light irrigation is done. Hand weeding by hand is easier in a machine.

Benefits of the technology

- It is water and carbon smart technology.
- There is no question of puddling and transplanting costs.
- Crop establishment is quicker.
- Crop's life cycle is relatively short.
- Yield is satisfactory.

Fig. 7 Dry direct sowing of rice drilled crops than in broadcast crops.

Limitations of the technology

- Weed infestation is a major issue in DSR technology.
- The availability and cost of herbicides is a major problem.
- DSR requires more seed than transplanting does.
- Early sowing is necessary for the DSR approach because plants need to emerge before the monsoon starts.

Fig. 8 Wet direct seeding of rice with a seed planter and a drum seeder

Adaptability rate

Direct rice seeding appears to be a potential option for rice farmers. The study shows that DSR technology has been adopted on 22.8% of the rice acreage on the surveyed farms (Younus et al., 2015). It has the ability to achieve high water efficiency while avoiding potential major conflicts in the rice-wheat cropping systems. Massive weed infestation is a barrier to the high-scale adoption of DSR. Weeds typically cause greater yield loss when they emerge sooner or at the same time as the crop.

Suitability to smallholder farmers

The rising cost of agriculture and diminishing profits with conventional transplanting practices are important reasons for increasing farmers' interest in DSR. All categories of farmers including smallholders are inclined to favor a technique that provides a better profit while yielding the same or slightly lower yield. Other advantages include quick crop establishment, a relatively short life cycle, and satisfactory paddy yield.

Success story of the technology

Younas et al. (2015) conducted in Sheikhupura, Lahore, and Kasur districts for an economic comparison of direct seeded rice (DSR) with transplanted super basmati rice during the 2014 kharif season. The average paddy yield, total cost of production, net economic benefits per hectare, and BCR for direct seeded rice were 3.09 t/ha, Rs.112,047, Rs.15,014, and 1.11, and for transplanted rice, they were 3.19, Rs.134,882, Rs.8,433 and 0.95, respectively. It was found that in 2014, farmers gained profit from practicing DSR technology and loss from transplanted rice crop. It was found that farmers were growing DSR through seven different sowing methods and using various seed rates. Better coordination between research, extension, and farming community can bring fruitful results with respect to the adoption to DSR technology.

Challenges for scaling up the technology

Obviously, it is a challenge to shift from a traditional puddled transplanted rice system to direct seeding of rice (DSR). Weed infestation is a big problem in direct-seeded rice. However, this can be controlled by the use of some safe weedicides e.g., glyphosate (trade name round-up) in the field before seeding rice. To maximize potential under DSR, both agronomic management and a good variety with acceptable features are required. Better coordination between research, extension, and the farming community can yield productive outcomes in terms of DSR technology uptake.

5.4 Mechanical Transplanting of Rice (MTR)

Introduction

Mechanical rice transplantation is the technique of transplanting young rice seedlings cultivated in a mat nursery using a self-propelled rice transplanter. One acre of planting requires 8 to 12 people in the traditional manual transplanting method while if a self-propelled rice transplanter is employed, three persons can transplant up to four acres of land in a day.

A rice transplanter is a type of transplanter designed specifically for planting rice seedlings in paddy areas. There are two types of rice transplanters - riding and walking. The riding kind is a powered and can often transplant six lines in a single pass. The walking type is a manually operated and can typically transplant four lines in a single pass.

A mat-type nursery is one that raises rice seedlings on a thin layer of soil and farmyard manure (FYM) or compost combination on a polythene sheet. The polythene sheet blocks seedling roots from reaching the underlying soil, resulting in a dense mat. This kind of nursery is required for machine transplanting. The mat can be cut into necessary shapes and sizes to fit into the transplanter's trays. Between 14-18 days, seedlings are ready for planting (DAS).

Guidelines for mechanical rice transplanting

- Use a harrow or cultivator to prepare the fields to a depth of 5-7 cm.
- Puddled fields should be leveled and the soil allowed to settle for 12-24 hours.
- In non-puddled situations, the soil should be tilled one or two times using a harrow or cultivator before being planked.

- Provide gentle watering and remove any surplus water prior to transplantation. Maintain a constant depth of 1-2 cm of standing water while planting.
- Seedling transplanting at the ideal age (14-18 days).
- Planting uniformity and optimal plant density (26-28 hills/m, with 2 to 3 seedlings/ hill).

Benefits of the technology

- Increased production (0.5-0.7 t/ha) when compared to traditional approaches in which plant spacing and density are not always consistent.
- Reduced transplanting stress, earlier seedling vigo, and uniform crop stand.
- Timely transplanting.
- Minimizes the labor shortage issue.
- Increases net income of farmers

Limitations of the technology

- Mat-type nursery work is time-consuming. The price of a mechanical transplanter (MT) is very high. There was a higher risk of younger seedling mortality in MT rice fields.
- Nursery raising, precise land leveling, and mechanical problems in machines are the limitations.
- The nursery raising with a specific technique is a major factor in arresting mechanical transplanting.
- Land leveling is also found an inhibiting factor in the technology. Being imported machinery, high price is also found an important factor.

Adaptability rate

Over the years, many efforts have been made to increase adaptability rate, but could not popularize for a number of reasons. The popularization of mechanical rice-culture in the country needs significant reforms in nursery raising, water management and land-preparation, along with emphasis on local manufacturing of the cost-effective simple mechanical rice transplanter.

To increase the adoption rate, the government under the Prime Minister's Agriculture Emergency Program (2019-2024) is distributing 450 Riding type MT 250 walk-after type MT, and 450 nursery-raising machines among the farmers. However, it is very inadequate for the whole country.

Suitability to the smallholder farmers

The MT technology is well fitted in the rice-wheat cropping system of the country. The adaptation of MT would give farmers the opportunity to increase the productivity of rice crop and their farm income by coping the issues like labor scarcity, less plant population, delays in transplanting with more aged nurseries, and improper fixation of nursery plants. However, machine cost and some technical matters (e.g., water in the field) are the barriers to its adoption.

Success story of the technology

In order to determine the economic viability and profitability of MTR, a field survey was carried out in the rice-wheat cropping system of Gujranwala zone, Pakistan, during Kharif season 2020. Due to lower adoption rate of MTR with a sample size of 240, the convenience and snow-ball non-probability sampling method was used. 72% of the targeted MTR growers used mechanical transplanters (MT) of the 6-row riding type, 18% used MTs of the 4-row walk-after type, and 10% used MTs of the 8-row riding type. With 47% and 38% of the rice area, respectively, Super Basmati and PK 386 were found to be more widely used varieties. Despite spending 6.17% more on operational costs for sowing and transplanting nurseries, an estimated MTR yield improvement of 11–13% and 16–20% higher net returns were achieved. The 292-303 values (variety-wise) of the marginal rate of returns (MRR %) were calculated for MT service users on a rental basis. As determined by the indicators such as benefit-cost ratio, net present value, internal rate of return, payback period (yr), and breakeven point (ha/yr), the project appraisal method of financial analysis illustrated the viability of MTR from the owner-user or service provider's point of view (Latif et al., 2022).

Challenges for scaling up the technology

Mechanical transplanting of rice is profitable over traditional methods and easy to operate. In spite of having superiority over conventional transplanting, acceptance in the yield, level is low due to high preliminary investment and lack of awareness in growing mat-type nurseries. The popularization of mechanical transplanting can be achieved through hiring planters from “Service Providers”, who can facilitate cultivation of paddy economically over conventional methods. Moreover, timely accessibility of machines may be some of the practical solutions to scale up the technology among the farmers.

Farooq et al. (2001) identified the most significant problems for MTR adoption as laborious seedling preparation, poor seedling fixation in soil, uprooting of seedlings by the wave action of machine movement, and 35-55% missing plantation according to Chaudhary et al. (2002), the adoption of MTR necessitated significant reforms in nursery raising, irrigation management, and land preparation, as well as an emphasis on local manufacturing of the cost-effective mechanical rice transplanter.

Fig. 9 Mechanical transplanting of rice

5.5 Zero Tillage for Wheat Sowing

Introduction

Fig. 10 Planting of wheat by zero tillage technology

Zero-tillage refers to the practice of sowing seeds directly into untilled soil after the previous crop has been harvested. The International Maize and Wheat Improvement Center (CIMMYT) introduced this technology. Utilizing the appropriate relay cropping system technology at zero-tillage is the best way to prevent delays in planting wheat after rice. The advancement of 'no-tillage' technology began in the early 80’s. On-farm trials, demonstrations, and pilot production projects using ‘no tillage’ methods were launched in the rice-growing districts of Gujrat, Gujranwala, and Sheikhupura as well as in the cotton-wheat-growing districts of Faisalabad, Jhang, Khenewal, Multan, Vehari, Bhawalpur, and D.G. Khan. Despite the fact that 'no-tillage' technologies have since spread throughout the NWFP and Sindh provinces.

Some important points for zero tillage:

- Depth for the seed should be 5 cm.
- Apply first irrigation after 15-20 days of sowing.
- Ensure that the standing stubble of rice is no longer than 15 cm.
- Use granular fertilizer so that pipes do not choke.
- Calibrate zero tillage machines to ensure the proper amount of seed and fertilizer.

Benefits of the technology

- Helps timely sowing.
- Saves fuel for no-tillage, about 20 liters of diesel is saved per acre.
- Reduces soil erosion.
- Increases soil organic matter.
- Reduces labor and time.
- Traps soil moisture to improve water availability.

Limitations of the technology

- Requires light irrigation.
- Occurrence of heavy rain during sowing time will disturb the operation.
- Uneven seeding may occur as many seeds are dropped when the operator stops.
- Uneven seeding leads to an uneven plant stand.
- Gap filling by manual seedling transplanting may be required.

Adaptability rate of the technology

The acceptance rate of 'no-tillage' technology at the farmer's level is yet to be improved. Any new technology must be compatible with existing farming methods and be consistent with farmers' interests and financial ability (Sheikh et al., 2003). It appears that in the cotton-wheat system personal characteristics like education, tenancy status, attitude toward risk implied in the use of new technologies, and contact with the extension agents were the main factors for adoption. In the case of the rice-wheat system, resource endowments such as farm size, access to 'no-tillage' drill, clay soils, the area sown to the rice-wheat sequence along with tenancy and contact with the extension agents were the dominant factors for adoption of this technology. Recently, with the increasing price of diesel, the use of this technology is gaining popularity.

Suitability to smallholder farmers

Zero Tillage Technology is a method of planting crops that does not require tillage or seedbed preparation. The tool used for this is known as Direct Drill or Zero Drill. This approach involves applying irrigation to rice fields before harvesting rice crop in mid-October. Wheat is sown with residual moisture by using zero tillage drills to avoid late sowing and save on field preparation costs. The rationale behind this method is to maximize profit by lowering tillage costs while maintaining yield. The technology suits smallholder farmers.

Success story of the technology

Wheat zero tillage technology is a unique method of growing crops that does not require tillage or seedbed preparation. Wheat is seeded in rice fields irrigated in mid-October using zero tillage drills to avoid late sowing and save on land preparation costs. Wheat sowing is generally delayed in rice-growing regions. Basmati rice, being a late-maturing variety, causes delayed wheat seeding. To avoid late wheat seeding, zero tillage technology was introduced in the Rice-Wheat system for on-time planting of wheat crop.

Tahir et al. (2008) conducted a study in the rice-growing districts of Sheikhupura, Gujranwala, Hafizabad, Sialkot, Narowal, and Lahore Punjab to evaluate the impact of Zero tillage technology in comparison to the different existing traditional wheat crop sowing methods. The results revealed more weeds in zero-tillage fields, thereby causing higher weedicide costs for the control of weeds. It was also found that the conventional method of wheat sowing is better and economically viable as compared to Zero tillage in terms of crop (wheat) yield in Punjab and Sindh, >25 manufacturers are currently producing this drill. The farmers are presently using about 6,000 drills. Saving 15 days for land preparation time has enabled timely wheat sowing, resulting in increased wheat productivity. In addition, it saves one irrigation and 60% wheat cultivation cost.

Challenges for scaling up the technology

No-tillage or zero technology can solve the issue of late planting of wheat crop in both rice-wheat and rice-cotton cropping systems. The study also indicated that Zero tillage technology has been adopted by relatively large farmers who can scarify yield by allocating some area to zero tillage to enhance the cost of production. There exist some barriers to large-scale adoption of this technology. The Department of Agriculture

Extension (DAE) has programs for farmers' training and field demonstration of this technology at farmer's fields.

Fig. 11 Zero tillage practice in wheat

5.6 Rice Mulcher for Residue Management

Introduction

Fig. 12. Use of rice mulcher for management of rice residues in the rice-wheat system

To address the issue of residue burning, Pakistan is promoting a number of technical solutions for ex-situ and in-situ residue management. These treatments assist farmers in preparing seedbeds and reducing environmental pollution caused by residue burning, however its acceptance is not wide. Crop residue burning is a simple, cost-effective, and time-efficient method of residue management, but it is not environmentally sound because it emits greenhouse gases such as, (CO_2, CH_4, & N_2O) and particulate matter, which contribute to global warming, air pollution, and climate change.

Rice plants mature in 4-5 months, depending on the varieties. Rice residues can be controlled more effectively with the advancement of new technology. Rice straw processing and management methods in Pakistan on a large scale can be classified as (i) *In-field/In-situ rice straw management***:** It is accomplished through either open field burning or incorporation into the soil, and (ii) *Off-field/Ex-situ rice straw management***:** It includes removing rice straw from the field for use for other purposes, such as mulching for other crops, bio-energy production, mushroom cultivation, cattle feed raw material, etc.

Residues are incorporated or mulched in-situ utilizing a Happy Seeder, Super straw management system, Paddy straw cutter cum spreader, Reversible moldboard plow, or No-till seeder. These approaches are profitable since they involve low cost and help higher crop yield. In-situ residue management, such as integration or mulching, enhances the physical, chemical, and biological properties of soil. Ex-situ residue management for biofuel, biochar, energy generation, or bale production is also environmentally a good practice and it minimizes pollutant emissions.

Benefits of the technology

- It is a carbon, nutrient, and water-smart CSA technology.
- Carbon sequestration occurs in soil.
- Soil fertility is improved.
- Soil moisture is retained in the soil.
- Helps timely planting of the next crop (e.g., wheat).

Limitations of the technology

- Burning of rice straw is very easy and simple, while the use of mulcher for residue management involves considerable costs.
- The beneficial effect of residue retention is not visible within a short time.
- It is a long-term effect.
- Weeds and disease organisms may harbor in residues.

Adaptability rate

The rice-wheat cropping system is the predominant farming system in all the provinces of Pakistan. The issue of late planting of wheat arises mainly in Punjab where particularly the basmati rice crop is grown. Burning of rice residue is done because of limited time availability for sowing of wheat seeds. However, the burning of rice residues has become a big environmental matter in the farming community. The current adoption rate of residue retention (one of three pillars of conservation agriculture) is quite low. However, researchers are working closely with the farmers, and through demonstration plots, they are trying to motivate the farmers about the soil health benefits of conservation agriculture (CA). Thus, the adaptability rate of this technology is expected to increase with time.

Suitability to smallholder farmers

Many farmers burn the rice residues for the timely planting of wheat crop. It is a huge loss of nutrients i.e., up to 80% of N, 25% of P, 21% of K, and 4-60% of S. This practice also contributes significantly to air pollution and the extinction of beneficial soil insects and microbes. However, the residue management technology with the use of residue mulcher is a very good practice. Nonetheless, smallholder farmers need financial support in any form - loan or subsidized price to harness the benefits of this technology.

Success story of the technology

Mr. Raja Javid, a progressive farmer from Markaz Haroonabad in the district of Bahawalnagar, was successful in obtaining a set of Rice Straw Shredder and Happy Seeder through an open ballot under the project MMRCR. He had planted rice on 100 acres of land. After crop harvest, he used a rice straw shredder in the field and expressed his satisfaction through the following words: "Previously, I was forced to dispose of unwanted rice crop remains by burning in the field, but after obtaining a rice straw shredder from the Agricultural Engineering Department, my long-standing critical issue has been resolved, and I am very grateful to the Government of Punjab for providing me with a very useful machinery at subsidized rates." I am now able to save a significant amount of time and energy by sowing wheat shortly after harvesting the rice crop."

Mr. Muhammad Shahbaz of Markaz is another progressive farmer: During the Balloting process, Lundianwala, Chak No. 586 GB, Tehsil Jaranwala, District: Faisalabad has also a success story. He had planted a rice crop on 25 acres of land. After using the Rice shredder and Happy seeder, the farmer expressed his feelings about the government initiative in the following way: "I had been using traditional methods for managing rice straw, but that was time-consuming and had negative environmental consequences." He was highly satisfied with field performances of the Rice Straw Shredder and Happy Seeder and believed that it is the best post-harvest solution for his field. He also stated that using Happy Seeder after shredder operation resulted in satisfactory wheat seed germination.

Fig. 13 Mulching of rice crop residues with residue mulcher before sowing of wheat crop

Challenges for scaling up the technology

In Pakistan and other countries of South Asia, rice and wheat straw are traditionally taken from the fields for use as livestock feed and some other purposes. Recently the farmers have started burning crop residues left in the field to avoid interference of crop residues with tillage. Weeds are unable to penetrate the barrier and obtain sunlight they require to sprout and thrive. Some people hold the idea that total cover burning is ideal for preventing the spread of diseases since residues could be a harbor of pathogens.

The residues, when burned, can produce up to 13 tons of CO_2 per hectare, polluting the air and robbing soils of organic matter. This suggests that South Asian farmers should handle 5 to 7 tons of rice residues per hectare while preventing burning and resolving issues with wheat planting. Many farmers prefer partial burning instead of full burning to get around the difficulties of raking loose straw during planting operations.

5.7 Rice Harvesting with Kubota

Introduction

Fig. 14 Harvesting of rice crop with Kubota Combine Harvester

Rice is one of the most important cereal crops of Pakistan. However, its traditional harvesting is labor-intensive and also time-consuming. To solve this issue use of a mechanical harvester is a good option. Kubota is a well-known brand of rice combine harvesters in Pakistan. Harvesting with Kubota is rapid and it decreases yield loss and increases farmer income. Kubota rice harvester streamlines the harvesting process by merging six tasks into one device, including gathering, transportation, reaping, threshing, cleaning, and bagging. It is the most recent and effective technique for harvesting rice. Kubota performs well in wet and dry fields, with outstanding work efficiency.

Benefits of the technology

- It is an energy-smart CSA technology.
- Income increases as the rate of grain loss is reduced from 10% to less than 1%.
- It can harvest up to 0.5-hectare land by one hour.
- The harvesting capacity ranges between 4 and 5 hectares per day.
- Kubota is capable of working in knee-deep mud as well as on extremely dry fields.
- Fuel consumption (Kubota DC-70 Plus) is extremely low, 7.5 liters per hour.

Limitations of the technology

- It is not fit to harvest a crop of a small size land.
- Most of the farmers have no ability to purchase this harvester.
- A portion of cropland although small is damaged by the harvester.

Adaptability rate

Kubota is a well-known brand of rice combine harvesters. They provide the most advanced agricultural Kubota Harvester types in Pakistan. However, the adaptability rate of the combine harvester is very low because of the high-cost involvement for the high price of the machine. Wide-scale adaptability is possible if government policy is adopted to give subsidies on the purchase of this instrument by a group of smallholder farmers.

Suitability to smallholder farmers

Kabota Combine Harvester is a time, labor, and cost-saving system along with reducing harvesting losses. As a result, the economic productivity of rice is greatly increased which contributes to farmers' income and livelihood status. Several questions as identified by Daum and Birner (2020), regarding the benefits of mechanization for smallholders. Nevertheless, the price of a combine harvester is very high which a smallholder farmer cannot afford. Of course, smallholder farmers can enjoy this advantage through service providers.

Success story of the technology

Mechanization of harvesting and threshing processes is recognized as a possible loss-reducing technique. Results of two studies indicate that losses in the case of combined harvester and for reaper use were 3% and 1.5% respectively. Manual threshing losses ranged from 1.45 to 11%, while mechanical threshing losses ranged from 1.01% to 3.15%. The results showed that substituting manual labor in rice harvesting and threshing with equipment enhances paddy output per hectare by 16.6% on average and significantly lowers greenhouse gas emissions. Cooperatively purchase of Kabota Harvester by a group of farmers is more cost-effective than renting, after a study of two harvests.

Challenges for scaling up the technology

Kubota is a well-known brand of rice combine harvesters. They provide the most advanced agricultural Kubota Harvester types in Pakistan. Mechanization increases production in a climate-friendly method while simultaneously providing a net financial advantage to the farmers. However, smallholder farmers have no ability to purchase this harvester. Thus, a government strategy is needed so that farmers in a group can buy it at a subsidized rate. Mechanization should be a component of any agricultural development strategy in developing countries, and that policy should encourage the appropriate level and type of mechanization to be available and accessible to smallholder farmers.

5.8 Raised Bed Furrow Irrigation in wheat

Introduction

This irrigation method involves dividing the soil surface into beds that are 40–130 cm broad and 10–20 cm tall, with 20–50 cm wide furrows running parallel to a field's slope or contours in between. Crops are sown on top of the beds, and water is supplied into the furrows to guarantee that the soil is kept at the optimum moisture level and that fields are equally watered. Raised bed furrow irrigation only requires modest quantities of water due to the field's limited wetted surface and strong hydraulic resistance. The designed surface encourages rainfall infiltration and collection, which reduces soil erosion and irrigation water requirements.

Benefits of the technology

- This technology falls under water-smart CSA technology.
- Compared to planting in a flatbed, furrow irrigated raised bed planting saves 30% to 50% of wheat seed.
- Improved drainage makes it feasible to grow highland crops more successfully during monsoon.
- Raised bed irrigation has been reported to use 28% less water and produce 27% more grains than conventional flatbed planting and comprehensive flooding techniques.
- Raised beds make herbicide application easier since they allow the person spraying to follow the line.

Limitations of the technology

- For water to reach the field's lower end, the furrow's length and width should be short and narrow since sandy soils quickly absorb water.
- Because the infiltration rate is poor in clay soils, the furrows should be deep and wide to help delay the water flow.

Adaptability rate

Ridge-furrow planting entails field preparation, seed broadcasting, and development of ridges and furrows with the ridger, whereas farmer practice entails land preparation, seed broadcasting, shallow cultivation with the cultivator, and planting. Wheat bed or ridge planting is being used in all four provinces of Pakistan, namely Punjab, Sindh, Khyber Pakhtunkhwa, and Baluchistan. However, wheat producers could use raised bed furrow irrigation systems provided (i) farmers are aware of the advantages of this technique, (ii) Financial support in the form of loans or subsidies is given to the farmers. Thus, the adaptability of this technology is low.

Suitability to smallholder farmers

Furrow-irrigated raised bed technology is an efficient irrigation method in which water moves through a furrow and crops planted on raised beds obtain moisture benefits. Due to water scarcity, farmers have shifted to a bed and furrow system for wheat planting. This technology is suitable for smallholder farmers provided they have access to this expensive machine. However, a government strategy for the promotion of mechanization would be a help in this regard. Growing wheat on furrow-irrigated raised beds is appropriate in areas where freshwater supplies are limited or water lifting is expensive, such as in winter crop production. The approach has significant advantages in areas where droughts occur often.

Success story of the technology

In the rice-wheat area of Pakistan, as compared to the conventional flat sowing, in a 70 cm bed and furrow system, more better wheat grain yield was observed, which was mainly due to the more spike length and higher number of grains per spike.

In order to plant four wheat rows on a 90 cm bed and furrow system, the Water Management Research Center at the University of Agriculture, Faisalabad, developed a bed and furrow planter. About 49% savings in irrigation timing and similarly 18% higher grain yield were recorded in the case of planting of wheat on raised beds as compared to the conventional flat sowing. Farmers who adopted this technology also benefited Rs. 17,000/ha and similarly, a 50% reduction in water use saved an additional expenditure of Rs.1,350/ha. 7 rows of wheat or 2 rows of maize were planted on a 180 cm bed and furrow by PARC and ACIAR, and they got a 30–32% increase in grain yield, and a reduction in water use was recorded.

Challenges for scaling up the technology

Although the technology of furrow irrigated raised bed cultivation has manifold advantages, it has some challenges. It is difficult to keep a raised bed for a long time due to the occurrence of monsoon rains on one hand and on the other hand, not all crops would fit to raised bed cultivation. Equipment cost and robust machines with high efficiency are also the challenges to obtaining full benefits of this technology. Raised bed planting requires careful variety selection.

Fig. 15 Wheat crop planted on raised bed furrow system

5.9 Raised Bed Planting of Maize and Cotton

Introduction

Construction of free-standing crop beds above the existing soil level is referred to as "raised bed farming" in agriculture. In order to create a closed planting bed, raised beds are occasionally covered with plastic mulch. For a raised bed to be effective, it should not be extremely deep. Farmers may only construct beds that are 8″ to 12″ deep, depending on the crops.

Raised bed-planting procedure for maize and cotton:

- Land leveling with a laser land leveler.
- Prepare the seedbed with one or two ploughings and one rotavation.
- Bed and furrow preparation and formation.
- Width of the bed should be 2 - 3 feet, and the furrows should be 1 foot.
- Use a bed planter to apply basal fertilizers (DAP and Urea).
- Use pure, healthy, and certified seed 6 to 8 kg per acre.
- Hand sowing two rows of cotton or maize (dibbling), keeping the plant-to-plant distance of 9 - 10 inches.

Benefits of the technology

- It is a water-smart CSA technology.
- Easy and effective irrigation water management.
- Requires 25-30% less water than normal.
- Crop yield is increased by more than 20%.
- Facilitates improved drainage system.
- Enables inter-bed mechanical weed control throughout the early crop cycle.
- Lowers the seed rate by 30-50%.
- No hardpan is developed, and the soil remains soft and safe.

- Increases fertilizer use efficiency.

Limitations of the technology

- It is not good for sandy soils.
- For water to reach the field's lower end, the furrow's length and width should be short and narrow.
- Because the infiltration rate is poor in clay soils, the furrows should be deep and wide to help delay the water flow.
- Total plant population would be less than the normal cultivation.

Adaptability rate

Due to the benefits as stated above, bed and furrow cotton planting has gained recognition and popularity among farmers in recent years, with more than 50% of cotton planted by using this method in addition to maize and wheat crops.

Efforts are now being made to promote crop production on Permanent Raised Beds (PRBs). The goals are to create a root zone for crops that absorb rain and irrigation water faster, make this water more accessible to plants, and allow plant roots to freely explore the soil for water and nutrients. A raised bed farming system achieves these soil properties by retaining root material from previous crops and practicing minimal soil disturbance with only a pre-seeding blade ploughing at 25 cm depth.

Suitability to the stallholder farmers

Switching to a raised crop bed saves money because it eliminates the need for an expensive drainage system. This system is equally applicable to the field crops, and vegetables. In the case of ridge-furrow planting of maize and cotton crops, the ridges and furrows that are developed with a ridger and cotton or maize crop are planted manually on the top or side of the ridge increasing cotton or maize crop germination. Similarly, yields of these crops are better as compared to the conventional flat sowing method, which is a commonly used method in Pakistan. Thus, this is suitable for all categories of farmers.

Success story of the technology

An additional benefit of bed planting becomes evident when beds are "permanent," that are, maintained throughout time rather than broken down for each crop. Creating permanent beds can assist in overcoming the restrictions of the present system's resource depletion and pollution. This has the potential to reduce the cost of rice-wheat farming by 20-25% when compared to traditional approaches. After harvesting of wheat crop, straw is either left or burned. A shovel is used to reshape the beds by passing it down the furrows. The following crop (soybean, maize, sunflower, cotton, etc.) can then be planted in the same bed into the stubble. The benefits of this method include lower expenses, erosion management, reduced soil compaction, and improved soil physical structure over time.

Permanent raised bed trials for rice-wheat, maize-wheat, cotton-wheat, soybean-wheat, and other rice-based cropping systems were conducted in Pakistan, with extra financing from ACIAR. This work also included the creation of locally built bed-forming machineries which is appropriate for local use and production. The 2014 ACIAR Adoption Study outlines the development of project LWR/2002/034 from 2004 to 2010, including alignment with the National Program to Encourage the Adoption of PRB Farming of the Pakistan Government (SAPRB). This research also identifies the factors that lead to a large number of farmers giving up on PRB, most notably inadequate equipment and/or lack of extension assistance for PRB farming and irrigation methods, as well as herbicide weed management.

Fig. 16 Maize and cotton crops planted on raised beds

Challenges for scaling up the technology

It is difficult to maintain a permanent raised bed which is threatened by monsoon rains and heavy irrigation. The bed system is not suitable for all crops. Equipment cost and robust machines with high efficiency are also the challenges for harnessing the full benefits of this technology. Raised bed planting requires careful variety selection.

5.10 Leaf Color Chart for Rice Crop

Introduction

Fig. 17. Use of Leaf Color Chart (LCC) for proper nitrogen fertilizer application to rice crop

The Leaf Color Chart (LCC) is used to calculate the nitrogen fertilizer requirements of rice crop. LCC features four green strips ranging in tint from bright green to dark green. It determines the greenness of the rice leaf, which shows the amount of nitrogen it contains. The LCC is developed by joint efforts of International Rice Research (IRRI) and Philippines Rice Research Institute (PhilliRice) from a Japanese prototype, with the goal of measuring the amount of nitrogen required in rice fields and thus achieving the maximum productivity.

Rice leaf nitrogen status is connected to photosynthetic rate and biomass output, and it is a sensitive indication of variations in crop nitrogen need during a growing season. A method for quickly assessing leaf N status and guiding fertilizer nitrogen application to maintain optimal leaf N content might therefore be critical for obtaining high rice output with effective nitrogen management.

How to use Leaf color chart (LCC)

*Plant selection for testing***:** Choose at least 10 disease-free rice plants at random from a field with a uniform plant population. Match the leaf color with chart: Choose the highest, youngest, fully developed leaf from each plant. This section best represents the plants' nitrogen status. Compare the color of the leaf's center section to the color panels. Do not remove or damage the leaf.

Measure the leaf color: Measure the leaf color in the shade of your body. Readings of leaf color are influenced by direct sunlight. If feasible, the LCC should be read by the same person at the same time every day. If the hue of a rice leaf is between two shades, use the average of the two values as the reading. For example, if the color is between 3 and 4, the reading should be 3.5. Determine the average, calculate the average of the 10 readings and if the value is greater than or less than three, a top-dressing of N fertilizer is required.

Benefits of the technology

- This technology belongs to nutrient smart category of CSA technology.
- LCC is not expensive compared to chlorophyll meter.
- It determines instant N deficiency or sufficiency or excess of rice crop.
- It saves the use of excess application of N fertilizer and thus, saves cost of fertilization.

Limitations of the technology

- This approach is mostly applicable to rice crop, not others.
- Same person and same time in every observation is a limitation.
- The LCC user might be color blind.

Adaptability rate

For effective fertilizer use and high rice yields, leaf color charts (LCC) presents significant opportunities for farmers to estimate plant nitrogen (N) demand in real time. Farmers typically apply N fertilizer in several split applications, but the quantity of N applied per split, the number of splits, and the timing of applications all vary significantly. The ability to synchronize N application with the current needs of the rice crop is made possible by the apparent flexibility of rice farmers in adjusting the timing and dosage of fertilizer application by using leaf color chart. Despite having many advantages, LCC is not popular among the farmers.

Suitability to the smallholder farmers

- The LCC is suitable for rice and also for maize and wheat, providing farmers with a good diagnostic tool for detecting nitrogen deficiency. The leaf color chart (LCC) is a novel and cost-effective tool for real-time or crop-need-based nitrogen management in rice, maize, and wheat.
- LCC is a valuable and subjective indicator of plant nitrogen deficiency, and it is a cheap, easy-to-use, and straightforward alternative to a chlorophyll meter.
- However, use of LCC at farmers’ level is far from expectation.
- Farmers always prefer a technology which is simple and convenient.
- This technology is suitable for all categories of farmers including smallholders.

Success story of the technology

The use of 120 kg N per hectare at LCC 4 reduced nitrous oxide emissions by 16% and methane emissions by 11% when compared to the traditional split application of urea in rice. In rice, however, applying N at LCC 5 increased nitrous oxide emissions by 11% compared to the LCC 4 treatment. Wheat nitrous oxide reduction at LCC 4 was 18% greater than the standard approach. The use of LCC-based N had no effect on carbon dioxide emissions from soil in rice or wheat. The global warming potential (GWP) in LCC 4 and conventional urea applications were 12,395 and 13,692 kg CO_2 ha^{-1} respectively. The total carbon fixed in conventional urea treatment in the rice-wheat system was 4.89 Mg C ha^{-1} and increased to 5.54 Mg C ha^{-1} in LCC-based urea application (LCC 4). According to the study, LCC-based urea spraying can reduce the GWP of a rice-wheat system by 10.5%.

According to Hussain et al. (2005), applying nitrogen to rice by looking at the LCC value at 14 days and 10 days following panicle initiation would save 40% more nitrogen than making a general suggestion.

Challenges for scaling up the technology

The main cause of the poor response of rice crop to nitrogen fertilizer is due to its low use efficiency (NUE), where it is only 30–40% of applied N is taken up by the crop, the rest is lost through some processes - ammonia volatilization, leaching, and denitrification. Agricultural soil is principally responsible for total worldwide anthropogenic N_2O emissions, accounting for more than one-third of total N_2O emissions (IPCC, 1999). Personal error in measuring plant N status is also a challenge.

5.11 Sensor-Based Nitrogen Management in Wheat

Introduction

The nitrogen (N) sensor-based technology is a real-time variable rate N sensor that allows farmers to detect crop N requirements as the fertilizer spreader goes over the field and modifies the fertilizer application rate accordingly.

Fig. 18 Sensor based nitrogen fertilizer management in wheat crop

Concerning the working principle of this sensor, the first step is to understand how the technology operates. Plant color is one way that plants can communicate whether they are nitrogen-sufficient or deficient. The more yellow they look, the less nitrogen they have. Even though the variations are undetectable to the human eye, canopy sensors are able to measure them. Using sensor-based nitrogen management, allow plants time to "sample" the nitrogen that is available in the soil before using plant greenness as a proxy to determine when to apply fertilizer at different rates over the season. Applying the bulk of the nitrogen rate at the side dress (an application of fertilizer between the rows of growing crops is known as a "side dress" application) can be achieved using sensor-based nitrogen management.

Agriculture sensor technology is based on the normal light reflectance curve for plants. This nitrogen sensor monitors light reflectance at certain wave bands that are connected to the chlorophyll content and biomass of the crop. It computes the crop's real N-uptake. The N-uptake data is used to calculate optimal application rates, which are then communicated to the controller of the variable rate spreader or sprayer, which adjusts fertilizer rates accordingly. The whole process of assessing the crop's nitrogen demand and applying the appropriate fertilizer rate occurs instantly, with no time lag. This makes "real-time agronomy" possible.

Benefits of the technology

- Nutrient-smart category of CSA technology.
- Delivers the best nitrogen fertilizer rate to every corner of the field.
- Increases agricultural potential throughout the field.
- Improves the effectiveness of fertilizer.
- Reduces harvest time and costs.
- Minimize the nitrogen leaks to the environment.
- Increases cereal crop yield by 3.5% when the same amount of fertilizer is applied.
- Nitrogen savings of up to 14%.
- Increases nitrogen use efficiency (NUE) and lowers the carbon footprint by 10-30%.
- Reduces crop lodging by 80% compared with crops where nitrogen is applied as a conventional practice.

Limitations of the technology

- It is crucial to understand the conditions that limit plant development, such as water stress, insect and disease outbreaks, and deficiency of other nutrients such as sulphur and magnesium which have identical effects on plant greenness as nitrogen stress.
- For instance, the yellowing of wheat leaves may be caused by insufficient soil aeration rather than a lack of nitrogen.
- Furthermore, while a canopy sensor can provide some insight into the current nitrogen status of the crop, it cannot predict the future availability of nitrogen in the soil.
- Meteorological variables may affect the sensor reading.
- Because of these difficulties, sensor-based nitrogen management cannot always produce accurate estimations of nitrogen requirements.
- There has lately been a lot of study done to integrate canopy sensing with other indications of soil nitrogen availability, such as crop models and soil nitrogen concentration, although their usefulness is still being investigated.

Adaptability rate

Although the technology (sensor-based nitrogen fertilizer application) looks sound and science-based, its adaptability and acceptability to farmers are minimal. Sensors should be sensitive enough to assess the nitrogen requirement of crops. It should be simple and farmer-friendly.

Suitability to smallholder farmers

For determining the N status of plants during the growth season, many kinds of optical sensing techniques have been developed. Nevertheless, these instruments cannot detect the crop's N concentration directly, they rely on measuring other substances, such as chlorophyll. With a variety of commercially accessible sensors and sensing methods, optical crop sensing is very simple to carry out. Remote sensing techniques allow for the delivery of this information in a timely, precise, and cost-effective manner. The nitrogen sensor was created to evaluate crop nitrogen status by monitoring the light reflectance qualities of crop canopies.

Success story of the technology

Wheat is planted on more than 9 million hectares in Pakistan each year. Of this, 85 percent is grown under irrigation farming systems. Farmers generally apply nearly 190 kilograms of nitrogen fertilizer per hectare of wheat.

Fig. 19 Use of Green Seeker for wheat crop for nitrogen fertilizer assessment management

More precise management of crop nutrients could increase farmers' profits by saving fertilizer with no loss of yield, as well as reducing the presence of excess nitrogen that turns into greenhouse gases.

Precision nutrient management means applying the right source of plant nutrients at the right rate, at the right time, and at the right place. CIMMYT-India and the Borlaug Institute for South Asia (BISA) have developed the application "urea calculator" for cell phones. In this process, a Green Seeker handheld crop sensor quickly assesses crop vigor and provides readings that are used by the urea calculator to furnish an optimal recommendation on the amount of nitrogen fertilizer the wheat crop needs.

This technology was evaluated and demonstrated in Pakistan as part of the CIMMYT-led Agricultural Innovation Program (AIP), supported by the United States Agency for

International Development (USAID) in collaboration with Pakistan partners. After conducting trials on over 100 farmer fields in Pakistan, the combination of crop sensors and urea calculator demonstrated that applying nitrogen at the 2nd irrigation stage (between 50-80 days after sowing) allowed for a reduction of 35 kilograms of nitrogen per hectare without compromising wheat grain yield.

Challenges for scaling up the technology

Sensor-based nitrogen requirement estimation depends on the technology's strengths and limitations. Canopy-sensing and side dress treatment can be postponed to later phases of growth. Sensor-based nitrogen management in rainfed fields can be profitable when compared to the Maximum Return to Nitrogen (MRTN) technique, but producers should be conscious of the technology's limits when establishing sensor and fertilizer application time. Precise estimation of crop nitrogen demand is increasingly crucial to increase growers' knowledge of and comprehension of the use of crop canopy sensors and in-field reference strips for efficient nitrogen (N) management.

5.12 Biofertilizer

Introduction

Biofertilizers are living bacteria that improve plant nutrition by mobilizing or increasing the availability of nutrients in soils. As biofertilizers, several microbial taxa, including beneficial bacteria and fungi, effectively colonies the rhizosphere, rhizoplane, or root interior. Biofertilizers also include mycorrhizal fungus and blue-green algae. Mycorrhizal fungi preferentially extract minerals from organic materials for the plant, whereas cyanobacteria (Bue-green algae) fix nitrogen. Nitrogen fixation is the process of turning di-nitrogen molecules into ammonia. For example, certain bacteria convert nitrogen to ammonia. As a result, nitrogen becomes accessible to plants. Nitrogen fixation can be either symbiotic or symbiotic. Bio fertilizer organically decomposes organic waste in the soil and releases nutrients in an easily absorbed form by plants.

Basic points of biofertilizers use

- For better microbial inoculum survival, development, and activity in acidic soils, sufficient volumes of organic manure (as per the requirements for each crop) and biofertilizers should be utilized.
- Liming is required if the pH of the soil is less than 6.0. For moderately acidic soils, 250 kg/ha of lime is advised in addition to bio-fertilizer treatment.
- After using bio-fertilizers in the summer, watering is necessary to ensure the life of the added bacteria.
- Full quantities of phosphorus and potassium may be administered as advised because N bio-fertilizers can only partially fulfill the inoculated plant's need for nitrogen.
- At least a week’s time needs to be allowed between applying chemical fertilizer and biofertilizer.

- Rhizobium and Bradyrhizoium root nodulation can be enhanced by the application of fine powdered calcium carbonate to moderately acidic soils with a pH of approximately 6.5.
- To ensure that Azolla grows well on phosphorus-deficient soils, it is advised to apply P2O5 at a rate of 1 kg/ha once every four days. When Azolla lacks phosphorus, it turns reddish-purple in color.
- Biofertilizers can be applied as field application, seedling root dip, foliar application, and set treatment (for sugarcane).

Benefits of the technology

- Biofertilizers are natural products containing live microorganisms, they prevent nitrogen depletion in soils and provide sustainable farming practices.
- It is an eco-friendly and sustainable solution to manage soil health, plant development, and the environment.
- These are less expensive and easier to use than chemical fertilizers.
- As a result, small and marginal farmers may create, manage, utilize, and recycle bio-fertilizers like Azolla and BGA as needed.
- They are pollution-free, run on renewable energy, are cost-effective, have a low-risk factor, and improve the efficacy of chemical fertilizers.
- Mycorrhizas (root-fungus association) increases P nutrition of plants.

Limitations of the technology

- A lot of nutrients are needed to supply externally for most of the crops.
- Quality of biofertilizers may deteriorate during long-term storage as they are living.
- Biofertilizers frequently undergo mutations when fermenting, which raises the cost of manufacturing and quality assurance.
- Efficiency of a biofertilizer may be reduced by using the wrong strain of microorganisms or polluting the carrier medium.
- Biofertilizers may lose their efficiency in dry soil and also in acid and alkaline soils.
- If there are too many antagonistic microbial foes present in the soil, biofertilizers might be ineffective.
- Biofertilizers cannot entirely replace chemical fertilizers.

Adaptability rate

Biofertilizers often contain bacteria that aid in nitrogen (N) fixation, phosphate solubilization, and other processes. These have the potential to play a significant role in the sustainability of the agricultural system. However, farmers may face certain issues, which can reduce the use of biofertilizers. These issues include unsuitable field performances, lack of standards and understanding of biofertilizer use, certain product quality, etc. If these issues are solved, its adaptability would become high and biofertilizers could be used on a large scale in the country.

Suitability to smallholder farmers

Concerning the cost involved, the acceptability of biofertilizer use is high for smallholder farmers. However, some technical matters such as microbial type, count, and activeness could discourage its use as it is not simple and understandable to a farmer. Further, it cannot fully replace the use of chemical fertilizers.

Success story of the technology

Rhizobium can fix 15-20% N/ha and increase pulse crop yield by 20%. They supplement fertilizer supply in order to fulfill crop nutrient demands. Rhizobium inoculation fixes 19 to 22 kilograms of nitrogen per hectare, Azotobacter and Azospirillum both fix 20 to 30 kg N ha^{-1}, Biogenic Glycerol may fix 20 to 30 kg N ha^{-1}, and Azolla inoculation fixes 3 to 4 kg N ha^{-1} per ton of Azolla inoculation. Two advantages of biofertilizers are the decomposition of organic wastes and soil mineralization.

Fig. 20 Biozote-Max, a bacteria-containing biofertilizer commercially available in Pakistan

A rhizobium specifically designed for chickpeas called Biozot was marketed by Pakistan Agricultural Research Council in association with Engro Chemical Pakistan Ltd. NIBGE markets Biopower as the brand name for their bio-fertilizer for rice. Moreover, provincial research institutes offer inoculums to farmers for both non-leguminous and leguminous crops.

Challenges for scaling up the technology

Production, supply, and availability of quality biofertilizers are the great challenges for its wide use in the country. The government could take up a strategy to provide effective extension services to farmers and motivate them to use bio-fertilizers in an integrated way with chemical fertilizers.

5.13 Use of Organic Fertilizers

Introduction

Organic fertilizers are naturally occurring mineral sources that supply a reasonable amount of plant-needed elements. They are capable of minimizing the issues connected with synthetic fertilizers. Organic fertilizers are made from natural sources (plants and animals) that degrade slowly and release nutrients into the soil. Its addition to soil influences the physical, chemical, and biological properties of soil.

There are several sources of organic fertilizers accessible in Pakistan that can be utilized to increase the organic matter content of soils. Organic fertilizers include farmyard manure, poultry manure, composts, green manure, crop residues, kitchen wastes, city wastes, bio-slurry, composts, etc.

Benefits of the technology

- Organic fertilizer practice is a carbon and nutrient-smart CSA technology.
- Its addition increases the organic matter content of the soil.
- Enhances the soil's water-holding capacity, improves soil structure, and decreases soil erosion.
- Supplies all nutrients, chiefly N, P & S.
- It is a food (carbon source) for heterotrophic microorganisms (N2 fixing bacteria viz. Rhizobium, Azotobacter) and earthworms.

According to a poll conducted by NFDC, 49% of farmers in Pakistan currently use the FYM. Some farmers use sesbania as a green manure crop on soils that are normally salt-affected as well as moderately affected by salt, and several studies have demonstrated the value of this technique. Cotton stick ploughing is becoming more popular among farmers when it comes to crop leftovers. The Pakistan Agriculture Research Council (PARC) is doing work on organic fertilization.

Limitations of the technology

- Market potential of organic fertilizers/manure is low.
- Few companies produce different composts, but the price is not affordable to the farmers.
- It contains a lot of nutrients, but its content on SOM is very minimal. Thus, a bulk volume of an organic fertilizer needs to be added which costs much more than chemical fertilizers.
- They are crop-specific and biological sources have their own drawbacks.

Adaptability rate

One reason for not adding organic wastes or fertilizers is the higher economic cost which is beyond the ability of the farmers. The farm animals are fed straw and other crop residues, but many farmers burn cow dung for cooking purposes. Green manuring is a very good practice, but farmers do not pay attention to it as it is not a crop and it does not give immediate financial benefits. The nutrient content of organic fertilizers is very low compared to chemical fertilizers, so a bulk amount (above 3 ton/ha) of an organic fertilizer needs to be added to the soil which ultimately enhances the cost of fertilizers. In this situation, the government's strategic decision is needed on how to add sufficient organic fertilizers to improve and sustain soil health.

Suitability to smallholder farmers

Every category of farmers would love to add organic fertilizers and organic manure to the soil, but its bulk application would cost much which a smallholder farmer cannot afford. However, the best approach to fertilizer management is the combined use of chemical fertilizers and organic fertilizers (IPNS or INM approach).

Success story of the technology

The combined application of inorganic and organic amendments like FYM, green manure, and residue straw improves their effectiveness (Yaduvanshi and Sharma, 2008). Results of a study, which was conducted in 2015 in Sindh and Punjab, reported that the use of potassium and micronutrients alone or in combination with farmyard manure, in addition to traditional NP fertilizers, increased crop yields. When NPK fertilizers, micronutrients, and manure were utilized instead of simply Urea, sugarcane yields increased by more than 60% in some circumstances (N).

Challenges for scaling up the technology

Pakistani soils have far less organic matter than the ideal condition and if a soil has 1.29% C, it is considered sufficient in organic matter. According to a survey done by Azam et al., (2001), the range of soil carbon in Pakistani soils is between 0.52 and 1.38% in various soil series and the majority of soils have less than 1% C. The most common soil orders in Pakistan are Aridisol and Entisol, which have the lowest organic matter status. The high temperatures in Pakistan promote fast decomposition and loss of organic materials. Hence, the enhancement of soil organic matter is highly difficult because of the sub-tropical humid climate.

Fig. 21 Different kinds of organic fertilizers in Pakistan

5.14 Green Manuring (Sesbania) in Rice-Wheat System

Introduction

Green manure is typically defined as a legume-based cover crop planted to improve soil fertility between two crops that require high nitrogen inputs. The use of green manure crops allows for the provision of 40-60% of the total N requirement of subsequent crops.

After incorporating these leguminous crops into the soil, organic N gradually decomposes and mineral N becomes available to plants for a longer period of growth. Growing green manure crops is known as "green manuring," and it is done to improve the fertility and health of the soil. This has been a long-standing tradition from the beginning of time. Green manuring practices have been disregarded since the Green Revolution's widespread use of chemical fertilizers, and farmers have paid a price for this neglect in the form of declining soil fertility.

Sesbania is an annual shrub that is native to South Africa and Asia and grows quickly, up to a height of 7 meters. This crop may grow in a variety of edapho-climatic settings. It is commonly used as a green manure crop to add nitrogen and organic matter to the soil. *Sesbania cannabina* (former name aculeata) and *S. rostrata* are the most common Sesbania species used in Asia (which produces nitrogen-fixing nodules in its roots). It is advised to plant 20 kg of Sesbania seed per hectare of ground. Sesbania grows very lushly, and 8 to 10 weeks after seeding, the crop may be absorbed into the soil. If it is planted before 55 to 60 days of rice cultivation, the results are optimal. A Sesbania crop that is 1-meter tall yields around 25 tons of fresh biomass per hectare and adds about 125 kg of fixed nitrogen to the soil. This considerably lessens the need for nitrogenous fertilizer.

Sesbania give organic matter and nitrogen benefits to the soil and subsequent crop development. Growing green manures provides a cheaper and renewable supply of N in some conditions, especially when limited infrastructure and transportation of nutrients (e.g., fertilizer) are expensive or not supplied on time.

Benefits of the technology

- This is a carbon and nutrient smart CSA technology.
- Green manure can add atmospheric N2 to soil
- Sesbania can produce up to 80-100 kg N/ha (equivalent to 4 - 5 t dry biomass of Sesbania per ha) in around 40 days during the long-day season and 50-60 days during the short-day season.
- It improves soil health, reduces soil erosion, and increases soil organic carbon pools.
- It takes up space on the soil surface, which prevents weed growth.
- Green manure effectively uses the nutrients left over from previous harvests and saves nutrients from leaching.

Limitations of the technology

- Low seed production.
- Increased labor requirements (for ploughing and incorporation of biomass into the soil).
- Photoperiod sensitivity of Sesbania.
- Competition for land and water with cash crops.
- Very low and very high lands are not fit to grow.

Adaptability rate

Sesbania as a green manure crop is well received by the farmers in Sindh. Farmers do not need to learn to grow Sesbania, it is just simply to adapt However, the growth and yield of Sesbania plantations in Pakistan can be improved further by using good planting materials and employing proper silvicultural and management techniques during plantation establishment and maintenance. In different areas of Pakistan, it is also used by the farmers as a feed for their livestock and especially for small ruminants.

Suitability to smallholder farmers

The use of Sesbania on a large scale for rice production can help reduce environmental pollution by lowering chemical N requirements and thus reducing greenhouse gas dispersal into the environment. When the green manure plants are about to flower, they can be cut and left or ploughed into the soil. Sesbania is used as a green manure crop for small-scale rice farming because it adapts well to irrigated and lowland environments. It is grown in a year in rotation with one or more crops. It can also be grown in rain-fed lowlands after the monsoon when the soil is sufficiently moist. The best time to cultivate Sesbania is from April to June, when there is typically unpredictable short-term water-logging. Obviously, the technology or practice is suitable for all categories of farmers, but the problem is that during this time farmers are not getting any crops.

Success story of the technology

Incorporation of sesbania in soil as green manuring has been a major barrier for its widespread adoption in the rice areas. To assess and compare the effects of different dhaincha accessions on soil health and grain yield of rice, nine dhaincha accessions were used as experimental materials along with a control (without dhaincha plant). The experiment was laid out in experimental plot and dhaincha was planted using the seed rate of 60 kg/ha. The 45-day-old dhaincha plants were mixed up with soil. Soil samples were collected before sowing and after decomposition of dhaincha biomass and analyzed following standard procedure. There was a substantial increase in soil organic matter (up to 26%), and total nitrogen content (up to 25%) in the soil after dhaincha incorporation 35 days old, healthy rice seedlings were transplanted in the dhaincha incorporated plots at the spacing of 15cm x 25cm (plot-plot x row x row). The results showed that grain yield increased (up to 39%) compared to the control. Among the dhaincha accessions, number 95 showed the best performance in terms of grain yield (Sarwar et al., 2017).

Challenges for scaling up the technology

Sesbania green manuring is an age-old practice. Its benefits are well recognized. Sesbania has the potential for multiple uses such as grain, fodder, and fuel, which can increase farmers' cash income, animal feed availability, soil productivity, and crop production sustainability. However, there are some challenges to scale up the technology. Of them, land suitability, land availability, seed availability and replacement of a crop are the major challenges.

Fig. 22 Sesbania green manuring in the rice-wheat cropping system

5.15 System Rice Intensification (SRI)

Introduction

System rice intensification (SRI) is an agro-ecological approach that simultaneously raises the productivity of the land, water, and capital in irrigated rice by changing the management of plants, soil, water, and nutrients. In a situation when resources are limited, SRI can aid in increasing production, reducing pollution, and supplying local food needs.

Fig. 23 Shifting of rice seedlings into the field

SRI began in Madagascar in 1986, and its concepts and methods have been confirmed in 41 countries with a wide range of agricultural systems and farm sizes. Since 2003, more than one million households in Vietnam, Cambodia, India, and Mali have used SRI techniques. Oxfam America is already advocating this approach in Haiti and developing it in Cambodia and Vietnam.

Basic features of SRI practices

- The field is first prepared by ploughing.
- Thereafter, 10 -12 days old healthy paddy plants with soil particles surrounding the root are transplanted in lines with minimal damage to the roots.
- Using irrigation at times rather than continuously flooding paddy fields.
- Employing hand weeders to aerate soils and eliminate weeds.

Benefits of the technology

- Water and knowledge-smart CSA technology.
- Higher yield of rice (15–20% increase).
- Shorter crop duration (by 10 days).
- Plant roots are not deprived of oxygen, irrigation is provided initially to keep soil moisture near saturation, and then water is delivered to the field when the surface soil develops hairline cracks.

Limitations of the technology

- More labor requirements in the beginning.
- When there is no irrigation supply, it is not appropriate.
- If unchecked, greater weed growth will cause a substantial loss of yield.
- It can be sustainable if organic inputs in the soil structure are maintained.
- There is a risk of establishment of 10-12 days young seedlings, especially in the winter.

Adaptability rate

The adoption of SRI method of rice cultivation is not yet popularized. Farmers prefer a technology that is robust, easy to handle, and economically sound. Farmers should receive training and visit the demonstration field which would help the farmers to make decisions.

Suitability to smallholder farmers

More than one million farmers and households in Vietnam and Cambodia have adopted SRI with the help of Oxfam and have made profits. Farmers have reported a significant yield improvement. There is a 90 percent decrease in seed requirement and a 50 percent reduction in water consumption. SRI principles can benefit millions of smallholder farmers since they are adaptable to a wide range of crops and environmental factors.

Success story of the technology

Project Drawdown's aim of 50 million hectares of SRI coverage by 2030 has been embraced by SRI-2030. This would improve rice production by 1 billion tons, cut CO_2 emissions by 8.5 billion tons, and raise farmer earnings by $1.6 trillion by 2050. SRI has reached more than 16% of the overall rice farming population in Vietnam's northern area, which is home to the majority of the country's small-scale, resource-poor rice farmers. During the year 2011 spring crop season, SRI farmers in Vietnam received an additional $17.6 million (VND 370 billion) (Oxfam.com).

Challenges for scaling up the technology

The technology is not yet very popular among the farmers. Seedling injury during cold periods may affect crop establishment and yield loss. Appropriate rice varieties are needed. Farmers should receive pertinent training and visits to the demonstration field that would help scale up the technology. SRI has primarily expanded through farmer-to-farmer networks and grassroots initiatives so far, but with more institutional support, it has the ability to scale much wider and much quicker.

5.16 Alternate Wetting and Drying (AWD) in Rice

Introduction

Water is supplied occasionally rather than continuously, also known as alternating wetting and drying (AWD). The AWD maintains the soil largely aerobic, which means more oxygen, enters the roots, promoting plant development and sustaining greater populations of beneficial soil organisms. This can reduce methane emissions by 30-70%. The International Rice Research Institute (IRRI) developed alternate wetting and drying (AWD) technology in 1970s as a smart water-saving technology for rice cultivation through national agricultural research systems and extension departments in different countries of South and Southeast Asia.

In Pakistan, the practice of AWD was first introduced in 2007 under ADB funded project, "Development and dissemination of water saving rice technologies for Southeast Asia." Altering water management practices, especially mid-season aeration by short- term drainage as well as alternate wetting and drying can highly control emission of GHG. Wetting and Drying (AWD) involves technology that tackles water scarcity in irrigated rice cultivation and has the potential to contribute to a sustainable and effective water and energy use.

Basic features of the technology:

- The method is based on inserting perforated tubes ‘Pani pipe’ into the soil to measure the height of the water table in the field.
- The water tube can be made of a 30 cm long plastic pipe or bamboo and should have a diameter of 10−15cm so that the water table is easily visible.
- When the water level has dropped to about 15cm below the surface of the soil, irrigation should be applied to re-flood the field to a depth of about 5cm till flowering.
- During grain filling and ripening, the water level can be allowed to drop again to 15cm below the soil surface.
- AWD can be started in 1−2 weeks after transplanting.
- In the case of a weedy field, AWD should be postponed for 2−3 weeks to suppress weeds by the ponded water and improve the efficacy of herbicide.
- The water level needs to be kept up to 5 cm below the soil surface at the time of flowering and grain filling.
- The number of days of non-flooded soil between irrigations can vary depending on a number of factors such as soil type, weather conditions, and crop growth stage.

Benefits of the technology

- AWD is a water, nutrient, and energy smart CSA technology.
- 15-30% of irrigation water can be saved in rice fields.
- AWD can help reduce methane emissions by 48% compared to continuous flooding.
- Nutrient availability increases for aeration due to the wetting-drying cycle.
- AWD is environment friendly and is assumed to reduce methane (CH4) emissions by an average of 48% compared to continuous flooding throughout the crop growth.

Limitations of the technology

- Installation of pipes in the field which might be stolen.
- Conflict arises between AWD farmer and irrigation service provider.
- Occasional rainfall may disturb the AWD system.

Adaptability rate

In the private sector, Engro Eximp disseminated AWD technology on a large scale in rice-growing areas of Sheikhupura, Gujranwala, Sialkot, Hafizabad, and Mandi Bahuddin districts and distributed “Pani pipes” among 10,000 farmers during years 2013 to 2015. In addition, more than 10,000 farmers witnessed AWD promotions in the area. Under the AIP project, 1,000 AWD water measuring pipes were distributed to farmers for the demonstration on one acre each in Sheikhupura, Hafizabad, Gujranwala, and Sialkot districts. These perforated water measuring tubes were manufactured locally and were distributed to farmers for the promotion of resource-saving technologies, demonstration plots were also established with the help of Agriculture Extension at the Adaptive Research Farm, Gujranwala, and Sheikhupura.

Suitability to smallholder farmers

The AWD practice can lower water use for irrigated rice by ~35% and increase rice yield by ~10% relative to permanent flooding. AWD method increases water productivity by 16.9% compared to continuous flood irrigation. This method can help increase grain yield because of enhancement in grain-filling rate, root growth, and remobilization of carbon reserves from vegetative tissues to grains. The technology is suitable for smallholder farmers since it does not involve much expense. However, conflict arises when a farmer takes irrigation service from a service provider.

Success story of the technology

Several studies also indicate that AWD can significantly reduce methane (CH_4) emissions. This method can also reduce insect pests and diseases. With the adoption of AWD, the cost of rice production is drastically reduced. Particularly, small farmers can benefit from AWD technology due to a reduction in energy and water costs. Water saving varied between locations and a maximum of 36% water saving was measured with AWD. Farmers saved Rs.3,000-4,000 per acre by reducing the cost of fuel and electricity. In AWD plots, the crop did not lodge and incremental paddy yield from 100-150 kg per acre was obtained. A study conducted by Tao Song et al., (2021) suggested that AWD might improve the nutritional performance of milled rice by increasing amino acids and phenolic acids and decreasing lipids and alkaloids.

Challenges for scaling up the technology

AWD can reduce the cost of irrigation by reducing pumping costs and fuel consumption. This method can also reduce labor costs by improving field conditions at harvest, allowing mechanical harvest. AWD is also expected to alter macro and micronutrient availability and uptake. Aerobic growth has been shown to favor enhanced selenium accumulation in rice, while decreasing arsenic uptake. Although the influence of AWD on water-saving potential and grain yield has been studied before, but its detailed effects on grain nutritional quality in milled rice remained relatively unexplored.

Fig. 24 Alternate wetting and drying (AWD) for rice cultivation

5.17 Short Duration Rice Varieties

Introduction

Pakistani short-duration rice cultivars that can withstand the circumstances that climate changes make more frequent and severe include excessive salt, as well as drought, flood, and heat tolerant varieties. Traditionally developed rice varieties need roughly 160-200 days for maturity and are quite susceptible to climate disturbances. However, the short-duration cultivars can be harvested in 110 to 125 days. Examples of short-duration rice varieties are Kissan Basmati (94 days), Punjab Basmati (80 days), Super Gold (105 days), KSK 133 (105 days) and KSK 434 (111 days).

Rice crop is grown all over Pakistan, especially in central Punjab, southern Punjab, upper Sindh, lower Sindh, Baluchistan, and Swat areas. The rice area is in increasing trend. Next to wheat, rice is the 2nd major staple food in the country. Its production comprises 34% basmati fine types and 66% course types. During 2021-22, the area under rice crop was 335,000 hectares with a production of 9.323 million tones.

Benefits of the technology

- It is a knowledge-smart CSA technology.
- It matures three weeks earlier than the commonly used rice varieties.
- It facilitates the timely growing of the next crop e.g., potato.

Limitations of the technology

- Generally, the yield potential of short-duration rice varieties is low compared to normal-duration varieties.
- Short-duration high-yielding characteristics of these varieties may not last long.
- Performances may vary with the agroecological zones, interrupted by climate variation.

Adaptability rate

Rice Research Institute, Kala Shah Kaku has developed 27 rice varieties as the institute is pioneer in generating extra-long, tasty, and aromatic rice (Basmati 370). The institute's rice varieties cover more than 90% of the Punjab's rice land. Rice is the country's second most significant cash crop after cotton, accounting for 11% of total planted land. Similarly, other research centers in the country are also developing new, high-yielding, disease-resistant and climate-resilient rice varieties for their target areas.

Suitability to smallholding farmers

The existing varieties do not produce a yield of more than five tons per hectare, however, the new variety would yield 12 tons per hectare. These would also mature 20 days earlier than the existing local varieties. Farmers can cultivate potatoes soon after the rice harvest at an early date. Farmers prefer early maturing, high-yielding varieties so that they can plant the next crop some days earlier.

Success story of the technology

Pakistan's value share of total world rice commerce is roughly 9.10%, and the country earns more than US$ 2 billion in foreign cash each year. Basmati rice is luxury rice that sells for around US $ 1,000 per ton, compared to US $ 450 for coarse rice on the worldwide market. In 2015, the Federal Ministry of Food Security and Research launched a project to increase yield and trade surpluses and requested Chinese assistance. As a result, improved hybrid seeds arrived in Pakistan and made a difference the following year in 2018. The three-pronged gain last year was the result of the same effort: the area rose by 6.4 percent, output climbed by 8.7 percent, and average yield increased from 825 kilograms per acre in 2010-11 to over 1,000 kilograms.

Challenges in scaling up the technology

In Pakistan, the rice industry is significant in terms of export profits, domestic employment, rural development, and poverty alleviation. Rice is both a food and a cash crop. Long-time holding of the high-yield potential of short-duration rice varieties in the country is a challenge in the changing climate situation.

Fig. 25 Short-duration rice variety IRRI-6.

5.18 Early Maturing Varieties of Maize

Introduction

In Pakistan, the maize crop is grown in an area of about 1.653 million hectares with a production of 10.635 million tones. It is the third-highest cereal crop in the country after wheat and rice. It contributes 3.2 percent value addition in agriculture and 0.7 percent in GDP. Its production is increasing with the passage of time, due to the availability of improved high-yielding varieties and better economic returns. Pakistan's maize industry marked a significant milestone in 2019 by commercializing 10 new maize varieties produced by the

Fig. 26 Development of early maturing maize varieties

International Maize and Wheat Improvement Center (CIMMYT). The Maize and Millets Research Institute (MMRI) in Yousaf Wala, one of Pakistan's premier and oldest maize research institutes has approved four CIMMYT-sourced open-pollinated varieties (OPVs). These varieties are Gohar-19, CIMMYT-PAK, Sahiwal Gold, and Pop-1, developed by the scientists of AYUB Agricultural Research Institute, Faisalabad.

All of these varieties have a short growing season which makes timely planting of the next crop. Maize can be grown both in the winter (main season) and summer (off-season). Early maturing crop types attain maturity after three months of sowing, protecting the crop from low rainfall or drought and can assist in mitigating the impact of climate change on agricultural operations. Crops that mature early might provide a rapid economic return.

Benefits of the technology

- These varieties attain maturity about three weeks earlier.
- The next crops maize and wheat could be easily grown.
- This is a knowledge-smart CSA technology.

Limitations of the technology

- Yield potential of short-duration maize varieties could be low compared to normal-duration varieties.
- Short-duration high-yielding characteristics of these varieties may not last long.
- Performances may vary with the agroecological zones.

Suitability to smallholder farmers

Early maturing varieties can enhance crop rotation in a very efficient way and can give huge economic benefits. These varieties help crop rotation in an efficient way. It reduces chances of crop failure and also boosts biodiversity. Maize is planted in rows 60 -75 cm apart, with plants spaced 20 to 25 cm apart. At harvest, a population of 60-75 thousand plants per hectare is necessary for the best yield. Sowing in rows is often accomplished with a drill or by dropping the seed behind the plough. Broadcasting is still practiced in many areas especially in the rainfed areas where maize crop is used as feed for livestock. For the grain crop, 17 to 20 kg/ha, while for fodder crop 35-40 kg/ha seed is required. Sowing of crop, a week to ten days earlier than the regular monsoon season, with an initial 1-2 irrigations can give a great support for proper crop establishment, and it can give 15-20% more crop production. For maize crop maximum production, a fertile, well-drained soil is required, but it can be grown in any type of soil, from deep heavy clays to light sandy soils, but the pH of the soil must not depart from the range of 7.5 to 8.5 because its plants especially seedlings are extremely sensitive to salt and water. Maize is mainly a warm-weather crop and it is cultivated in a wide range of climatic conditions across the world, from tropical to temperate. It is extensively grown from sea level to heights of 2,500 meters. It grows well if the night temperature does not fall below 15.6 degrees Celsius. It cannot tolerate cold at any stage of its development.

Adaptability rate

Maize is now competing with other important *Kharif* crops like cotton and rice. Due to a number of issues, including lack of irrigation water, climatic issues, availability of seed to the growers, input shortages, unstable prices, etc., exist in several districts of Punjab and Sindh that are known for their cotton production have revolted against producing cotton and instead prefer to grow maize and other vegetable crops. The Vehari district is well known for producing cotton in Punjab and it is said that Vehari alone produced equal to 80% of total Sindh province cotton production and now recently revolted against cotton in favor of maize. Maize crop is now giving double the income to the farmers as compared to the cotton crop because this crop needs a short time for its maturity. It is mostly grown in Punjab and KPK provinces of Pakistan and these two provinces produce more than 97% of the country's total maize crop production while Sindh and Baluchistan produce only 2 to 3% of maize grains. The maize crop is also gaining popularity in Azad Kashmir, and now more than 0.122 million hectares area is under this crop.

Success story of the technology

The Agricultural Innovation Program (AIP) for Pakistan, directed by CIMMYT and financed by USAID, in collaboration with the different research partner's institutes has been helping the small holding farmers across the country by providing them the excellent maize seeds. Over the last six years, AIP's public and private partners have been able to obtain from CIMMYT and IITA over 60 finished maize products and more than 150 parental lines for further testing variety registration, demonstration, and seed scale-up. In 2020, the Federal committee fixed a target for maize crop production of 5,012,000 tons, but the actual production was 7,800,000 tons.

Challenges for scaling up the technology

Unexpected and heavy rainfall is a factor that reduces *Kharif* crop productivity. Similarly, during fertilization and pollination, water stress has a significant impact on maize production. Irrigation water plays a vital role in getting the maximum yield of maize crop and a study shows that a single lack of irrigation at the sensitive stage of maize crop development can reduce its 40% maize grains. Pakistan is also facing water shortage issues and according to international experts, Pakistan will be a water-scarce country by 2025. Generally, the high temperature has little effect on maize pollination or kernel growth. However, when soil moisture is sufficient, high temperatures have an effect on maize crop and similarly drought stresses its pollination. Soil fertility is declining with the advancement of time, which results in low crop yield. Nitrogen and phosphorus are the most critical nutrients for increasing maize crop productivity. To improve soil fertility and to increase crop output, the right choice for maize varieties is very important and the amount of macro and micronutrients should be applied according to the crop's need.

Maize is a nutritious crop. It contains 72% starch, 10% protein, 4% oil, 5.8% fiber, 3% sugar, 3% vitamins A and B, and 1.7% ash. Maize is a dominant crop in Pakistan. The poultry sector consumes around 60% of total maize production, while wet milling and other companies consume 25%. The leftover maize is harvested as food and fodder for humans and animals. Around 45% of the maize crop is utilized for silage. The need for maize crops for silage production is increasing with the passage of time. There is a need to improve local production of cultivated varieties of maize and hybrid maize so that these are freely available to the farmers having lower production costs while maintaining average output.

5.19. Pest Resistant Varieties of Onion & Cotton in Punjab and Sindh

Introduction

Onion (*Allium cepa* L) is an important vegetable crop that is used in all households around the year. Its green leaves and immature and mature bulbs are eaten raw or used in cooking. Onions are also used to flavor soups, sauces, and other dishes. A recent study suggests that eating onions may help avoid heat stress and some diseases. *Thrips tabaci* (Lindeman.) is a major insect pest that attacks onion crops in all stages of growth. Although onions are grown all across Sindh; Mirpurkhas, Umerkot, Jamshoro, Matiari, Sanghar, and Shaheed Benazirabad have the highest production. These areas of Sindh supply around 71% of the total production of the province. Variety Chiltan-89 only was found to be Thrips-resistant and it has been recommended for commercial cultivation.

Pakistan is the 5th largest producer of cotton (*Gossypiun Hirsutum L.)* in the world and the textile products have a share of around 60% in overall exports of the country. Its seed accounts for 80 percent of the national production of oil seed. It contributes around 0.6% to GDP and 2.4% of the value added in agriculture. Cotton is attacked by numerous insect pests and viral diseases in Pakistan (Ahmad et al., 2002). Throughout the world, Bt-cotton, also known as genetically modified cotton (transgenic, resistant to lepidopteran insects), has been introduced in many parts of the world to fight against bollworms. According to a study (Abdullah et al., 2010), bollworm resistance in newly created cultivars has to be reinforced with additional management strategies within the framework of IPM.

Benefits/advantages of the technology

Ecological compatibility and compatibility with other direct control strategies are major advantages of using insect-resistant crop varieties as a component of IPM. Insect-resistant cultivars enhance the effectiveness of natural, biological, and cultural insect pest-control methods. The "built-in" protection of resistant plants against insect pests works on a very basic level, disrupting the insect pest's normal association with its host plant. This is a knowledge-smart technology.

Limitations of the technology

Pests may develop resistance to the toxins produced by the crops, resulting in a reduction in crop production.

Adaptability rate

Farmers in Pakistan were greatly helped when "Bt-cotton" (genetically modified, transgenic, and insect-resistant) was introduced because it reduced the harm done by bollworms. 'Bt-cotton' is resistant to bollworms but has no effect on sucking pests. After the introduction of "Bt-cotton," the risk of damage from bollworms, particularly Heliothis armigera, was reduced, however, the pink bollworm problem is still an issue.

Suitability to smallholder farmers

The use of insect-resistant crop varieties is advantageous economically, ecologically, and environmentally. Crop yields are saved from insect pest losses, and money is saved by not applying insecticides that would have been applied to susceptible varieties. In most cases, the seed of insect-resistant cultivars costs the same as the seed of susceptible cultivars.

Increases in species diversity promote ecosystem stability, resulting in a more sustainable system that is less polluted and harmful to natural resources. Thus, it is a suitable technology for the smallholder farmers.

Success story of the technology

A research study was carried out between 2008 and 2010 to assess the vulnerability of onion crops to a widely recognized onion pest, Thrips tabaci Lindeman. The results showed that genotype "VRIO-3" was particularly sensitive, with 181.7 thrips per plant. With 94.2 thrips per plant, the genotype "Desi Large" was moderately resistant. A survey regarding the susceptibility of onion cultivars reported a scarcity of thrips-resistant types in Punjab. To fight against the threat of thrips assault, thrips-resistant cultivars must be developed. The highest ginning-out turns were also noted for the cultivars "BS-52," "VH-305," "RH-647," "IUB," and "AA-919". FH-Lalazar gave the highest seed-cotton yield during the two study years and in comparison to the other cultivars, it showed low pest susceptibility and CLCuV infestation. 'FH-Lalazar' and 'RH-647' were found to have the highest and lowest gross and net incomes as well as benefit-cost ratios, respectively. The 'FH-Lalazar' can be suggested for higher yield and financial returns in Multan due to its low pest susceptibility and high seed-cotton yield.

Challenges for scaling up the technology

Recent research suggests that "Bt-cotton" is losing its resistance to bollworms. Pink bollworms are also persistently resistant to Bt cotton. In Pakistan, excessive quantities of insecticides are used to manage cotton pests. Although insecticides are essential for pest control, their careless use affects the viability of agro-ecosystems. However, insecticides can have a negative impact on the environment, natural enemies, and human health. By using new cultivars and better management techniques in cotton and onion, the output may be increased. Reducing post-harvest onion losses, making value-added onion products, and similarly to cotton and onion exports, Pakistan can earn a lot of foreign exchange.

Fig. 27 High-yielding pest-resistant varieties of onion and cotton

5.20 Zero Tillage Happy Seeder / Pak Seeder for Wheat Planting in Combine Harvested Rice

Introduction

Wheat in Pakistan is planted on more than 9 million hectares each year in wheat-based cropping systems viz. cotton–wheat, rice-wheat, maize-wheat, sugarcane-wheat, and rainfed wheat. In Pakistan, rice is grown on 2.79 million ha in Pakistan including 1.30 million ha under Basmati rice varieties in the province of Punjab. Wheat crop is planted in 2.2-million-hectare area after rice crop in the country. More than 80% of rice fields are combined harvested in Punjab leaving a large amount of standing as well as loose residue in the field. After rice harvest, farmers typically burn rice residues, generating large noxious clouds, and drive tractor-drawn plows repeatedly over fields to prepare seed beds. They then sow wheat seeds through broadcasting.

CIMMYT-led Agricultural Innovation Program (AIP), supported by the United States Agency for Development (USAID) evaluated zero tillage "Happy Seeders" on farmer's fields in rice-wheat districts of Punjab by experts from the Punjab Agriculture Research and Extension Department, Engro Fertilizer, and machinery manufacturers. In ZT happy seeder wheat planting, wheat planting, and fertilizer application can be done through a single pass of ZTHS without burning rice residue in combine harvested rice field. ZTHS can plant one acre in 1-1.3 hours depending upon the rice residue quantity present in the field.

Benefits/advantages of the technology

Management of surface residues, tillage, and water has an impact on soil carbon reserves. While soil carbon content is maintained in submerged rice fields, it rapidly decreases in frequently tilled, aerated systems, especially when residues are removed or burned. While switching to zero-tillage farming may decrease respiration and increase soil carbon stocks, switching to more aerated soils for rice will result in lower carbon stock levels.

Limitations of the technology

- Occurrence of heavy rain during sowing time will disturb the operation.
- Uneven seeding may occur as many seeds are dropped when the operator stops.
- Uneven seeding leads to an uneven plant stand.

Fig. 28. Sowing of wheat crop by using Happy seeder after rice crop

Adaptability rate

Sharif Engineering, a zero-tillage seed drill manufacturer of the Faisalabad region, modified the Zero till Happy Seeder so that farmers were able to sow wheat directly into heavy rice residue fields and thus avoid burning the residues and decreasing GHG emissions. During 2016 and 2017, Sharif Engineering manufactured 25 Happy Seeders with AIP support and these were sold to farmers on a cost-sharing basis.

Now these ZTHS have transportation wheels that can also be used as depth-controlling wheels in the field. Zero till Happy seeder technology helps farmers to get 0.2 t/ha more yield and reduce 70% cost of land preparation with zero till happy seeder in comparison with farmer practice. Presently more than 100 ZTHS are working in rice-wheat area Punjab, Pakistan.

Suitability to smallholder farmers

Zero-tillage Happy Seeder / Pak Seeder was found to be successful resource-saving technology in rice-wheat systems. It helps the farmers to avoid burning of rice residue and plant wheat timely in single operation. Zero tillage wheat is ideal for rice-wheat systems because it allows for earlier wheat planting, aids in weed control, lowers production costs, and saves water. The combination of a 'yield effect' (a 5-7% yield boost, primarily owing to more timely planting of wheat) and a 'cost savings effect primarily tillage savings offers large benefits at the farm level. Thus, smallholder farmers can adopt this technology.

Success story of the technology

In the "rice-wheat" cropping system, late planting of wheat is mainly due to the late harvesting of previous rice crops, particularly the premium rice variety "Basmati." Now with the combined harvesting of rice, burning of residue added to environmental pollution. The adoption of ZTHS and Pak Seeder can help to decrease environmental pollution and GHG emissions.

Challenges for scaling up the technology

High price of the Seeders is the main hurdle in the upscaling of these environmentally friendly seeders among the farming community. Provision of financial support to farmers and agriculture service providers can help in upscaling the technology.

5.21 Crop Calendar

Introduction

A crop calendar is a schedule of the growing season for the crops, starting with the fallow period and land preparation, followed by the establishment and maintenance of the crop, and finally the harvest and storage. A crop calendar enables better cost and activity planning for all farm tasks.

Fig. 29 Crop calendar for timely planting of crops

The crop calendar is a tool that may be used to improve agricultural output and extension operations as well as the recovery of farming systems following catastrophes. Information is now available for more than 100 crops. The corresponding national authorities verify all of the data.

Crop Calendar of Pakistan

Crop calendar of different field crops, vegetable crops and fruits is given below

Table 2. Crop calendar of different field crops, vegetable crops and fruits

Sr. #	Crop Name	Common Name	Scientific Name	Seed Rate	Sowing Date	Transplanting Date	Harvesting Date
1	Rice	Chawal	*Oryza sativa*	7-8 kg	15 May-Jun	15 Jun-20 Jul	Nov
2	Wheat	Gandam	*Triticum aestivum*	50-60 kg	15 Oct-Nov		15Mar-15 Apr
3	Barley	Jau	*Hordeum vulgare*	35-40 kg	15 Oct-Nov		15Mar-15 Apr
4	Maize	Makaee	*Zea mays*	12-16 kg	Oct-Dec		Apr-May
					End Jul		Nov-Dec
5	Cotton	kappas	*Gossypium hirsutum*	8-10 kg	May-Jun		15 Sep-Nov
6	Mustard & Rapseed	Sarson	*Brassica campestris* ssp.	1.5-2 kg	15 Sep-Nov		Apr-May
					Aug-Sep		Dec
7	Soybean	Soya-bean	*Glycine max*	28-32 kg	Jan-Feb		June
					Jul-Aug		Nov
8	Groundnut	Mong-phali	*Arachis hypogaea*	25-30 kg	March-Apr		Aug-Sep
9	Sunflower	Sooraj-mukhi	*Helianthus annuus*	2.5-3 kg	Feb-Mar		Jun-Jul
					Jun-Aug		Nov-Dec
10	Safflower	Kosamba	*Carthamus tinctorius*	6-8 kg	Oct-Nov		Apr-May
11	Sesame	Till	*Sesamum indicum*	1-1.5 kg	Jun-Jul		Nov-Dec
12	Sugarcane	Ganna	*Saccharum officinarum*	100-120 Monds	Sep-Feb		Nov-Mar
13	Sugarbeet	Chukandar	*Beta vulgaris*	1.5-2kg	Sep-Nov		Mar-May
14	Sorghum	Jowar	*Sorghum bicolor*	8-10 kg	June-jul		Sep-Oct
15	Linseed	Ulsi	*Linum usitatissimum*	6-8 kg	15 Oct-15 Nov		End Apr
16	Lentil	Masoor	*Lens culinaris*	8-10 kg	Oct-Dec		Apr-May
17	Gram	Channa	*Cicer arietinum*	20-25 kg	Oct-Nov		Mar-Apr
18	Millet	Baajra	*Pennisetum glaucum*	1.5-2 kg	15 Jul-Aug		1 Nov-15 Nov
19	Mung Bean	Mung	*Vigna mungo*	8-10 kg	Jul-Oct		Mar-Jun
20	Mash Bean	Mash	*Vigna radiate*	8-10 kg	May-Jun		Aug-Sep
21	Broad Bean	Lobia	*Vicia faba*	20-25 kg	Oct-Nov		Mar-Apr
					Feb-Apr		Jul-Aug
22	Tobacco	Tobacco	*Nicotiana tabacum*	3-3.5 kg	Oct-Dec		Apr-May
23	Carom Seed	Ajwain	*Trachyspermum ammi*	2-3 kg	Nov-Dec		Mar-Apr
24	Alfalfa	Lucern	*Medicago sativa*	5-7 kg	Oct-Nov		Jun-Jul
					Mar-Apr		Sep-Oct
25	Barseem	Barseem	*Trifolium alexandrinum*	8-10 kg	Sep-Nov		Feb-Mar
Vegetable and Fruits Calendar							
Sr. #	**Vegetables & Fruits Name**	**Common Name**	**Scientific Name**	**Seed Rate**	**Sowing Date**	**Transpalnting Date**	**Harvesting Date**
1	Potato	Aalo	*Solanum tuberosum*	1200-1400 kg	Sep-Oct		Jan-Feb
					15-Feb-Mar		Apr-May
2	Tomato	Tamatar	*Solanum lycopersicum*	120-150 grams	Oct-Nov	Dec-Feb	Apr-Jun
3	Onion	Piyaz	*Allium cepa*	4-5 kg	Jul-Aug	Sep	Nov-Mar
4	Garlic	Lehsan	*Allium sativum*	250-350 kg	Oct		Apr-May
5	Ginger	Adrak	*Zingiber officinale*	480-720 kg	Mar-Apr		Oct-Nov
6	Peas	Matar	*Pisum sativum*	20-30 kg	Sep-Oct		Dec-Jan
					Nov		Feb-Mar
7	Carrot	Gaajar	*Daucus carota*	4-5 kg	Sep-Oct		Dec-Mar
8	Chillies	Marach	*Capsicum annuum*	200-380 grams	Oct-Nov	Feb	May-Jul
					May-Jun	Jun-Jul	Sep-Nov
9	Cabbage	Band-gobi	*Brassica oleracea*	200-300 grams	Sep-Oct	Oct-Nov	Nov-May
10	Cucumber	Kheera	*Cucumis sativus*	300-500 grams	Feb-Mar		Apr-May
					Jul-Aug		Sep-Oct
11	Coriander	Dhaniya	*Coriandrum sativum*	6-8 kg	Oct-Nov		Mar-Apr
12	Cauliflower	Phool-gobi	*Brassica oleracea*	0.5-1 kg	May-Jun	Jul	Dec-Jan
					Jul,Aug, Sep	Aug,Sep,Oct	Feb-Mar
13	Brinjal	Baingan	*Solanum melongena*	200-250 grams	Nov,Feb,Jun	Feb,Apr,Aug	Apr,Jun,Sep
14	Broccoli	Broccoli	*Brassica oleracea*	250-300 grams	Sep-Nov		Feb-Mar

15	Bitter Gourd	Karela	*Momordica charantia*	2-3.5 kg	Mar-Apr		May-Jun
					Jun-Jul		Aug-Sep
16	Bottle Gourd	Lauki	*Lagenaria siceraria*	2-2.5 kg	Feb-Mar		Apr-Jun
					Jun-Jul		Aug-Sep
17	Spinach	Palak	*Spinacia oleracea*	10-15 kg	Jun-Nov		Aug-Mar
18	Sponge Gourd	Torai	*Luffa aegyptiaca*	1-2 kg	Mar-Apr		May-Jun
					Jun-Jul		Aug-Sep
19	Sweet Potato	Shakarkandi	*Ipomoea batatas*	30,000 Cuttings	Nov	Feb-Mar	Jul
					Mar	Jun-Jul	Nov
20	Radish	Mooli	*Raphanus sativus*	2.4-3 kg	Sep-Nov		Oct-Mar
					Jul-Aug		Aug-Oct
21	Turnip	Shaljam	*Brassica rapa*	1-2kg	Aug-Nov		Oct-Mar
22	Turmeric	Haldi	*Curcuma longa*	600-700 grams	Mar-Apr		Dec-Mar
23	Apple Gourd	Tinda	*Praecitrullus fistulosus*	500-700 grams	Mar-Apr		Jun-Jul
24	Fenugreek	Methi	*Trigonella foenum-graecum*	3-4 kg	Oct-Nov		Jun-Mar
25	Field Vetch	Gowar	*Vicia sativa*	9-11 kg	15-Apr		Oct
26	Lettuce	Salad	*Lactuca sativa*	0.8-1 kg	Feb-Apr		Jun-Jul
27	Lady-finger	Bhindi	*Abelmoschus esculentus*	2-3 kg	Feb-Mar		Apr-May
28	Kholrabi	Kholrabi	*Brassica oleracea*	1.5-2 kg	Dec-Jan		Mar-Apr
29	Arum	Arvi	*Arum italicum*	300-400 kg tuber	Feb-Mar		Aug-Sep
30	Mango	Aam	*Mangifera indica*	75-100 Trees	Feb-Mar		Jun-Jul
31	Orange	Narangi	*Citrus sinensis*	100-150 Trees	Feb-Mar		Nov-Feb
32	Olive	Zaitoon	*Olea europaea*	200-350 Trees	Feb-Oct		Sep-Oct
33	Apple	Saib	*Malus domestica*	50-100 Trees	Feb-Mar		Nov-Dec
34	Appricot	Khobani	*Prunus armeniaca*	109-134 Trees	Dec-Mar		Jul-Aug
35	Almond	Badam	*Prunus dulcis*	110-116 Trees	Nov-Dec		Sep-Oct
36	Avocado	Makhanphal	*Persea americana*	150-165 Trees	Feb-Mar		Oct-Nov
37	Grapes	Angoor	*Vitis vinifera*	500-600 plants	Jan-Feb		Mar-Jun
38	Guava	Amrood	*Psidium guajava*	108-135 Trees	Mar-Apr		Feb-Mar
					-		Aug-Sep
39	Pear	Nashpati	*Pyrus communis*	150-270 Trees	Feb-Marc		Jun-Jul
40	Peach	Aarhu	*Prunus persica*	100-110 Trees	Jan-Feb		Apr-May
41	Plums	Aulo-bokhara	*Prunus domestica*	100-110 Trees	Jan-Mar		May-Sep
42	Papaya	Papeeta	*Carica papaya*	800-900 Trees	Feb-Mar	Apr	Dec-Jun
43	Phalsa	Phalsa	*Grewia asiatica*	680-900 Plants	Aug-Sep		May-Jul
44	Pomegranate	Anar	*Punica granatum*	100-250 Trees	Dec-Jun		Sep-Feb
45	Pummelo	Chukotra	*Citrus maxima*	85-95 Trees	Feb-Mar		Sep-Nov
46	Banana	Kela	*Musa sapientum*	350-400 Plants	Feb-Mar		Aug-Sep
					Aug-Sep		Feb-Apr
47	Loquat	Loquat	*Eriobotrya japonica*	150-161 Trees	Feb-Mar		Mar-Apr
48	Lychee	Lychee	*Litchi chinensis*	50-100 Trees	Aug-Sep		Jun-Jul
49	Lemon	Lemon	*Citrus limon*	210-250 Plants	Jul-Aug		May-Jun
50	Lotus	Kanwal	*Nelumbo nucifera*	4-5 Kg	Jun-Aug		Apr-Sep
51	Watermellon	Turbooz	*Citrullus lanatus*	120-400 grams	Jan-Mar		Apr-Jul
52	Walnut	Akhrote	*Juglans regia*	300-680 Trees	Mar-Apr		Aug-Oct
53	Cashew-nut	Kaajoo	*Anacardium occidentale*	200-350 Trees	Apr-Jun		Feb-May
54	Coconut-palm	Nariyal	*Cocos nucifera*	45-55 Trees	Jul-Aug		Dec-Nov
55	Cherry	Cherry	*Prunus avium*	200-360 Trees	Mar-Apr		May-Jul
56	Dates	Khajor	*Phoenix dactylifera*	85-120 Trees	Feb-Mar		Jul-Sep
57	Fig	injeer	*Ficus carica*	150-260 Trees	Mar-Apr		Aug-Sep
58	Jaman	Jaman	*Syzygium cumini*	55-80 Trees	Apr-May		Feb-Mar
59	Jujube	Ber	*Ziziphus mauritiana*	100-110 Trees	Mar-Apr		Feb-Mar
							May-Jun

Benefits/advantages of the technology

The primary goal of a crop calendar is to predict the timing of cultural practices for various crops. Additional goals are listed below:

- determine the correct time for sowing and harvesting various crops.
- help in financial management.
- aid in the equitable division of labor.
- aid in effective crop management.
- determine the best time to apply fertilizer and insecticides.

Limitations of the technology

Climate change is a big threat to maintaining calendar-based farm activities. Unusual temperature variation and rainfall magnitude and distribution would affect the crop calendar. In coastal areas, natural disasters like cyclones, tsunami have an impact on the crop calendar.

Adaptability rate

Crop system management takes into account the complex decisions between all cropping systems in one field. Rotations, intercropping, and multi-cropping are common techniques used in smallholder farms all over the world because they can produce more revenue than monocultures. The likelihood of maximizing yield gains and minimizing or even eliminating potential tradeoffs between economic profitability and environmental sustainability increased when cropping systems are managed by crop calendar. Agronomic and environmental synergies between different crop systems could be amplified through "collective and collaborative" adjustments and adaptations, which would also boost the overall climate resilience of the systems being managed.

Suitability to the smallholder farmers

The crop calendar could be horizontal, vertical, and circular type. To create a crop calendar, crop production activities are required in chronological order, usually in tabular form under certain major headings. Land preparation, sowing/planting time, intercultural operation, harvesting, post-harvest operation, and so on are examples. Time is commonly measured in months for the sake of convenience. Because the time of a specific operation may extend into a different month, it must be noted in the crop calendar properly.

Success story of the technology

Sustainable agricultural practices involve a variety of approaches. The most important approach for sustainable agricultural development is crop diversification, which allows farmers to employ biological cycles to minimize inputs, conserve the resource base, maximize yields, and reduce the risk due to ecological and environmental factors (Barman, 2022).

The results of studies also revealed that timely rice system modifications are necessary for the timely planting of wheat crop. Wheat and rice are the main two crops that are planted in the same field in the study area, and managing these co-cropped systems necessitates difficult decision-making that could result in production or environmental trade-offs. Crop calendar management techniques are being used to boost wheat yield without reducing rice production. The scenario analysis shows that when adjustments are made to the coupled rice-wheat calendar, wheat yield productivity and farmer profitability gains are significantly higher than when adjustments are made to the calendar of the rice or wheat systems separately.

5.22 Drought Tolerant Wheat Varieties

Introduction

Fig. 30. Field trials for development of drought tolerant wheat varieties

Wheat is a staple food for the people of Pakistan, and drought is a great constraint for its production. The average wheat production in Pakistan is 2.9 metric tons per hectare, which is relatively low compared to other countries such as China (5.8 t/ha), Egypt (6.4 t/ha), and Mexico (5.6 t/ha). Pakistan is located in dry and semi-arid climatic zones and is experiencing significant and escalating irrigation water shortages. Thus, development and use of drought tolerant wheat varieties deserve much attention for obtaining higher and sustainable yield of wheat.

Table 3. A list of drought-tolerant wheat varieties in Pakistan

Sl. No.	Wheat varieties	Year of Release	Adopted Areas
1	Wafaq-23	2023	KPK
2	Taskeen-22	2022	Punjab
3	Umid-e-Khas-21	2021	Baluchistan
4	Pirsabak-21	2021	KPK
5	NIA Shaheen	2020	Sindh
6	Markaz-19	2019	Punjab
7	Aghaz-19	2019	Baluchistan
8	Barani-17	2017	Punjab
9	Wadan-17	2017	KPK
10	Kohat-17	2017	KPK
11	Ehsan 16	2016	Punjab
12	Fateh Jang-16	2016	Punjab
13	Borlaug-16	2016	Punjab
14	Shalkot-15	2015	Baluchistan
15	AZRC-1	2014	KPK
16	Umeed-14	2014	Baluchistan
17	Pakistan-13	2013	Punjab
18	Shahkar-13	2013	KPK
19	NIFA-LALMA-12	2012	KPK
20	Dharabi-11	2011	Punjab
21	Tijaban-10	2010	Baluchistan
22	BARS-09	2009	KPK
23	NARC-09	2009	Punjab
24	Chakwal-50	2008	Punjab

Sl. No.	Wheat varieties	Year of Release	Adopted Areas
25	Faisalabad-08	2008	Punjab
26	G.A-02	2002	Punjab
27	Chakwal-97	1997	Punjab
28	Kohsar-95	1995	Punjab
29	Pothwar-93	1994	Punjab
30	Inqlab-91	1991	Punjab
31	Rawal-87	1987	Punjab
32	Chakwal-86	1986	Punjab

Benefits and limitations

Wheat yield is declining due to some abiotic stresses, especially heat and drought. Most losses are minimized due to sensitivity during the reproductive phase in heat and drought-prone agriculture. Because yield is an endpoint distorted by the stressor, it is utilized as a yard stick for measuring these stresses. Abiotic dynamics, heat in low latitude zones, and drought stress typical in most arid and semi-arid zones are estimated to cause 50% production losses in agricultural crops. Thus, development and use of drought tolerant wheat varieties are an advantage for sustainable wheat production. Availability of such varieties to the farmers may become a limitation.

Suitability of the technology

In Pakistan, wheat crop is grown an area of about 9.0 million hectares, of which about 7.5 million hectare is irrigated, while 1.5 million hectare is rainfed. Average yield of wheat crop in Pakistan is about 2.9 tons/ha. The potential of wheat varieties available in Pakistan is more than 8.0 tons per hectare and progressive farmers are getting more than 6.0 tones/ha yield, but due to climatic factors, less use of certified seed and improper use of nutrients are the main reasons for average low yield. Wheat is mainly grown in rice-wheat, cotton-wheat, maize-wheat, sugarcane-wheat and rainfed-wheat cropping systems.

Adaptability rate

Climate change stress on wheat production means farmers urgently require more heat and drought-tolerant types. Wheat scientists used an innovative approach that combined genetic diversity with physiological and molecular breeding and bio-informatics technologies to produce several successful results, including three lines of wheat varieties specifically bred for increased tolerance to heat and drought in Pakistan.

Drought stress is a significant danger to global wheat production. Wheat genotype adaptability to drought stress is an important goal in wheat breeding. Drought is a significant concern for plant breeders all around the world. Plant breeders must produce cultivars that can withstand such stress conditions without considerable yield loss in order to feed the world's growing population under such environmental conditions. Using more drought-tolerant seed varieties is one of the key CSA measures practiced in Pakistan. Obviously, adaptability rate and farmer’s adoption of drought tolerance varieties of wheat are at high level.

Impact and suitability to smallholder farmers

More than 100,000 Pakistani farmers plant more than three varieties of wheat. This credit goes to the Pakistan Agricultural Research Council (PARC) and different institutes working with wheat crop and to the international centers i.e., CIMMYT and ICARDA and similarly to the seed corporations and seed companies.

Success story of the technology

With the generous support of CIMMYT and ICARDA, Pakistani scientists are continuously working for the development of new wheat varieties for the different ecologies of the country and up till now more than 200 wheat varieties have been approved for general cultivation. In every season at least 30 different wheat varieties are cultivated in the country and this diversification is very important to compete against the different wheat plant diseases and different environmental hazards. Three lines specifically bred for heat and drought resistance wheat varieties approved for general cultivation during last few years include Kohat-17, Borlaug-2016, Pakistan-2013 and Wafaq-2023 etc. Farmers earn 34% more grain output when they plant new varieties with certified seed as compared to farmers home saved seed. Recently released wheat variety NIA-Shaheen for Sindh province is also tolerant to diseases and lodging. It has bold grain and has exceptional quality. This variety also performs well in water stress condition. Similarly, Tijaban-10, a drought-tolerant wheat variety developed by the Arid Zone Research Centre Quetta for the rainfed (i.e., Sailaba / Khushkaba) areas of Baluchistan. This is a semi dwarf variety and has great tillering potential and excellent drought tolerance.

Challenges for scaling up the technology

Water is critical for the smooth operation of many metabolic functions within plants. Plant growth and development are significantly reduced in the absence of water. Water scarcity in arid and semi-arid regions is a major challenge for sustainable agriculture around the world. Drought reduces wheat output significantly in semi-arid locations. According to statistics, drought stress affects around 99 million hectares in underdeveloped nations and 60 million hectares in industrialized ones. Water scarcity affects 15 million hectares of land in Pakistan. Lack of water supply to wheat can reduce its productivity up to 17 to 70%. Growing drought-tolerant wheat genotypes could be a long-term solution for increasing wheat productivity under drought-stress circumstances. Development of drought-tolerant high-yielding wheat varieties and its long-time constant performances is a great challenge.

5.23 Green Manuring in Wheat

Introduction

Green manure is typically thought of as a legume-based cover crop used to improve soil fertility in between two crops that require substantial nitrogen inputs. Green manure crops can supply between 40 and 60 percent of the total N needed by succeeding crops. When these leguminous crops are added to the

Fig. 31 Green manuring for soil fertility improvement

soil, organic nitrogen progressively breaks down, leaving mineral nitrogen available to plants for a longer growth period.

Benefits of the technology

- This is carbon and nutrient-smart technology.
- GM crops collect nutrients from deeper soil layers and deposit them on the topsoil.
- Green manuring promotes the activity of soil microorganisms, and many of them are beneficial.
- When green material decomposes, it releases organic acids that increase the availability of plant nutrients such as phosphorus, calcium, potassium, magnesium, and iron.
- Green manures should be harvested as soon as they begin to bloom, generally after 7-8 weeks.
- It enhances the soil's water-holding capacity and soil aeration.
- It decreases soil erosion.
- It decreases soil bulk density.

Limitations of the technology

- In rainfed conditions, proper breakdown of the green plant materials and adequate germination of the subsequent crop may not occur if sufficient soil moisture is not available.
- The practice of green manuring may not be economic, particularly in areas where irrigation infrastructure and fertilizers are readily accessible.
- Green manure crops may bring some insects, bugs, and nematodes that might affect the next crop.

Adaptability rate

Farmers frequently recognize the benefits of green manure crops, but many do not utilize them because they do not know which green manure species to employ or how to incorporate them into their own cropping system. As a result, it is critical to prepare ahead of time where and when green manure crops will be cultivated. The timing of sowing is critical. Before the next crop is planted, the green manure must be ready to be ploughed in. The time between burying the green manure and sowing the following crop should not be too long. This is done to keep nutrients from green manure from draining out of the soil and being taken up by the fellow crops.

Suitability to smallholder farmers

From May to June, seeds can be planted for a green manure crop that can be ploughed down the soil in July. It should be ploughed down into the soil after it reaches the blooming stage, which occurs around 7-8 weeks after seeding. Dhaincha achieves optimum growth 8 weeks after seeding, while Sunnhemp crops blossom 8-10 weeks after sowing. Sunnhemp, dhaincha, cowpea, greengram, blackgram, etc. can be used as green manure before the wheat is grown in the fields. For green manuring, it is typically advised to use a greater seed rate. The factors that determine the suitability for use as a green manure are the cost of seed, labor, land, irrigation, and its fitness to the cropping system. However, this is a suitable technology for smallholder farmers.

Success story of the technology

Khan et al. (2022) reported that in very low organic matter soils, the soil is inert and cannot sustain productivity. Pakistan's soil fertility situation exhibits low organic matter status, low nitrogen concentration, and low usage efficiency. This project began in 2017-18 with the goal of increasing soil nitrogen content and organic matter by green manuring and increasing N usage efficiency under Quetta's agroecological conditions. This experiment included five treatments (T1 = Green manuring (GM). T2 = GM +25% recommended N (30 kg N /ha). T3 = GM+50% N (60 kg N/ha). T4 = GM+75% N (90 kg N/ha). T5 = GM+100% N (120 kg N/ha). Three replications based on randomized full block design (RCBD). The findings showed that when 75 and 100% of the necessary N was sprayed on wheat crops following green manuring, all the research parameters—aside from plant height and chlorophyll contents—improved. While both 75% and 100% N expressed statistically at par differences for wheat characteristics and yield, green manuring assisted in raising soil N levels when 75% suggested N was applied. Green manuring also boosted NUE by 68.9, 147.0, 126.2, and 100.8% at various N percentages (25, 50, 75, and 100%). Just green manuring, however, did not provide enough nitrogen to wheat crops without the use of nitrogen fertilizer. The use of N fertilizer to the wheat crop is therefore implied to have improved soil organic matter and total nitrogen because of the use of green manuring.

It was reported that green manuring improved soil N levels when 75% of the necessary N was applied, because both 75 and 100% N produced statistically significant variations in wheat characteristics and production (Khan et al., 2022). Furthermore, green manuring enhanced NUE by 68.9, 147.0, 126.2, and 100.8% at varied N percentages (25, 50, 75, and 100%).

Challenges for scaling up the technology

Green manuring is a low-cost and effective technology in minimizing cost of inorganic N fertilizer and safeguarding soil productivity. Nevertheless, Initial setbacks may be seen in field crops after the incorporation of organic residues with a wide C-N ratio. In this situation, there would be a competition between microbes and plants for nitrogen acquisition. High lignin content which resists easy decomposition and release of a higher proportion of organic acids during the decomposition of green manure crops adversely affects the establishment of young seedlings. It can be overcome by the extra addition of nitrogen.

5.24 Mung / Soybean in Fallow -Wheat Rainfed System

Introduction

In Pakistan, mungbean (*Vigna radiata* L) and mashbean (*Vigna mungo* L) are significant pulse crops farmed and consumed. Legume crops also help cereal crops such as wheat grow by enhancing soil organic matter and physical qualities. Growing legumes in less fertile soil may enhance soil health by fixing atmospheric N and may augment the usage of inorganic fertilizers.

Fig. 32 Mungbean-wheat crop rotation

The current trend of growing demand and pricing for pulses such as mungbean and mashbean has offered an opportunity for farmers to enhance their farm income.

Cereal-legume intercropping is thought to be the finest strategy for basic food production. Intercropping is becoming more common among small producers since it gives a yield advantage over mono-cropping through output stability and meeting diverse home demands.

Benefits of the technology

- This technology is knowledge smart category.
- Weed control, yield stability, grain quality, and minimum favorable yield are all important criteria for farmers.
- Cereal-legume intercropping is common in tropical climates and rain-fed areas across the world.
- Intercropping promotion can have benefits of increased productivity, soil conservation, and weed control.
- It reduces parasitic diseases of legume roots and produces high-quality feed.
- Crop combinations also have many more positive impacts on the soil and plants than negative ones, which might have an impact on root systems and production.
- Higher carbon returns to the soil lead to carbon enrichment, which increases the amount of organic matter in the soil.
- For resources, cereal-legume intercropping involves intra- and interspecific competition both above and below ground.

Limitations of the technology

- Facilitation or competition might be feasible in intercropping systems.
- When compared to cereal planting alone, competition is the most important factor influencing yield among combinations.
- In rain-fed environments, seeding ratios, species or selections, and inter and intraspecific competition may all have an impact on the development of intercropped species.

- Because of the lack of rhizospheric investigations in mixes, complicated and time-consuming interactions in cereal-legume cropping systems have received little attention.

Adaptability rate

Wheat is the most important crop, serving as a raw material for associated industries in Pakistan. However, food security remains in danger when rainfed areas contribute less than the objective. In such cases, a system combining several practices of soil fertility maintenance and improving land use efficiency was necessary. This includes the use of mineral fertilizers, organic manures, and intercropping for a long-term, environmentally safe, commercially successful, socially viable, and ecologically sustainable agricultural system. Farmers are now interested in intercropping because of the increased production and economic benefits.

Suitability to smallholder farmers

Farmers can use intercropping to address nature's concept of diversity on their fields. Different intercropping systems, such as strip cropping, mixed intercropping, and classic intercropping, have been investigated. In this setting, intercropping provides a strategy for increasing yields per unit area, diversifying food, and lowering crop failure risk under rainfed conditions. Intercropping or growing multiple species simultaneously in the same field is a cropping strategy that results in more stable yields, frequently leads to more efficient use of resources, and is a way to reduce weed issues, minimize nitrogen losses, and reduce the pressure of plant pathogens. Choose systems that are effective, productive, and economically feasible to achieve these; under such situations, cereal-legume intercropping systems are important for the effective use of resources. The technology has merits of its adoption by the smallholder farmers.

Success story of the technology

It is recognized that there has ecological significance of soil organic matter in overcoming barriers to crop growth, particularly in the areas of nutrient supply, nutrient and moisture relation, soil structural stability, and detoxification, despite some researchers' comments that it was not a requirement for plant growth in and of itself. For the purpose of determining sustainability, information is also required to evaluate the role that organic matter plays in preserving the soil microbial community, which is in turn related to specific enzymatic reactions, or biochemical processes, involved in various nutrient cycling. Nevertheless, some studies that used legumes as green manures to support cereals have promising outcomes. In dryland systems, this technique appears to be ineffective. The use of soil moisture by a previous summer crop, which reduced the amount of soil moisture available, is one factor in cereals' decreased responses. Crop selection and crop succession are important elements in creating cropping systems that achieve higher water use efficiency. Various legumes from around the world need to be investigated to see if they can be used as cover crops in fallow rainfed wheat systems.

Challenges for scaling up the technology

Inorganic fertilizers are being used carelessly by farmers to increase crop yields and address the issue of nutrient deficit. It is reported that Pakistan's alkaline soils responded well to chemical fertilizers, enhancing agricultural yield. The ineffective technique of application and the improper usage of chemical fertilizers are blamed for the poor fertilizer use efficiency. The constant use of artificial fertilizers has caused the soil's fertility to decline, which has been a major obstacle to maintaining agricultural yield. Legume-based crop rotation has the advantage of sustaining soil fertility and crop productivity. In continuous wheat systems, growing water-efficient legumes for green N could be a viable replacement for summer fallow and help lower production costs related to recent increases in the price of inorganic fertilizers

Fig. 33 Soybean-wheat crop rotation

5.25 Deep Tillage / Chisel Plow for Fallow Moisture Conservation

Introduction

Tillage is a method of preparing the soil for crop production by modifying it. The goal is to regulate soil properties such as water retention, temperature, infiltration, and evapotranspiration. Tillage techniques are often categorized as either primary or secondary. Primary tillage is practically deep tillage and secondary tillage works at a shallower level. for fertilizer incorporation and weed management. Deep tillage can boost agricultural yields in hardpan soils. This causes water ponding at the soil surface and/or greater runoff, resulting in poor moisture conservation. Furthermore, the hardpan layer limits the amount of soil that plant roots may exploit for moisture and nutrients. Crop moisture and nutrient stress are prevalent in hardpan soils, especially in dry years.

Conventional tillage not only destroys soil and water resources but also has an impact on agricultural output sustainability. The primary contributors to hardpan development are continual cropping and the tractor tire inflation procedure. Soil compaction (e.g. bulk density) must be reduced in order to generate healthy soil tilth. Soil compaction has a negative impact because it reduces porosity, restricts root development, and results in poor plant growth and production.

Benefits of the technology

- This technology falls into carbon and energy smart CSA technology.
- Tillage aids in the incorporation of organic matter and nutrients into the soil, increasing its fertility and absorbing these elements into crops.

- Deep tillage helps increase soil moisture content. However, the benefit of deep tillage in dry farming relies on the rainfall pattern and crop.
- Ploughing aerates and loosens the soil, allowing the roots to eventually grow deeper and deeper.
- Microbial activities and their interactions with crop harvest leftovers and soil organic matter are thought to be aided by tillage.
- Deep tillage provides exposure to hot sun, which kills the rhizomes and tubers of perennial weeds.
- Deep tillage of 25-30 cm depth is required for deep-rooted crops such as pigeon pea, whereas maize requires moderate deep tillage of 15-20 cm depth.
- Deep tillage practices are quite effective in preserving soil moisture contents through precipitation and its utilization by the groundnut which is a deep-rooted crop.

Limitations of the technology

- One significant disadvantage of tillage is that it contributes to global warming due to carbon dioxide emissions into the atmosphere. So, minimum and no-tillage is an advantage for the reduction of GHG emissions.
- Deep tillage is not convenient for saline soils because it promotes evaporation and causes salts from the subsoil to rise to the surface.
- Deep tillage also facilitates soil erosion.

Suitability of the technology

In Pakistan's dryland Pothwar area, where agricultural production is severely constrained by water availability, the climate ranges from semi-arid to sub-humid, and subtropical continental. Rainfall is erratic and subject to large geographical and temporal variations; 70% of it falls during the summer monsoon when temperatures can reach 50°C. Additionally, the fallow season is six months long and entails extensive conventional tillage techniques. Regular tillage in the area involves heavy moldboard-plough ploughing, repeated tine cultivator cultivation for weed control, and planking for seedbed preparation. These practices lead to physical soil disintegration, oxidation, and microbial decomposition of soil organic matter and structural aggregates, as well as hard pan formation that prevents water infiltration and plant root entry.

Moisture absorption is affected by the amount and timing of rainfall, the rate of evaporation, and the kind and physical state of the soil. Rainfed (barani) fields, which account for 20% of cultivated area, are located in Agro Ecological Region (Punjab-V), where rainfall ranges from 1,000 mm year^{-1} in the north-east to 200 mm in the south-west, necessitating extensive ploughing to increase moisture infiltration (Hobbs et al., 1986).

Adaptability rate

In Pakistan, farmers are progressively shifting their preferences towards the usage of tractors and other technology. By creating an ideal environment for seedling establishment and fully absorbing fertilizers and pesticides into the soil while suppressing weeds, farmers utilize deep tillage to ensure the success of their crop harvests. Adaptability rate is not high because its cost of operation is high.

Success story of the technology

A field study was conducted in 2014 (4th year) in a medium–term conservation tillage experiment at Pothwar dry land area Rawalpindi, Pakistan. The treatments were arranged in a split-plot design having Minimum tillage (MT), Chisel Plough (CP), Zero tillage (ZT), Conventional tillage (CT Control), and residue retained and residue removed were kept as subplots. Field capacity and permanent wilting point were highest under Chisel plow (35.6%) and 8.3% respectively while lowest under Zero tillage (23.9% and 6.0%) respectively. The highest infiltration rate was also under Chisel plow (196.5 mm/h) and lowest under Zero tillage (29.5 mmh^{-1}). Consequently, volume water content was significantly higher in the Chisel plow as compared with all other treatments at 0-15cm and 15-30cm depth during the crop period (Asghar et al., 2017).

Abu-Hamdeh (2003) conducted a field experiment to assess the impact of different tillage depths on soil characteristics and wheat productivity. Rotavator, modified rotavator, spade cultivator, chisel plough, and combination of chisel and rotavator were all tested in this study. The results revealed that penetration resistance (PR) was 0.31 MPa at the top layer (0-10 cm) with chisel plough + rotavator and 2.46 MPa at depth 20-30 cm with a rotavator. The bulk density produced by the spade cultivator is about the same for the whole depth range of 0-30 cm, ranging from 1.16 to 1.23 MPa. With a spade cultivator, the minimum bulk density was found to be 1.23 g cm^{-3} at a depth of 20–30 cm, while the highest was found to be 1.99 g cm^{-3} with a rotavator. The use of a spade cultivator with a mini-tiller produced the maximum wheat grain yield of 4,070 kg per hectare. Deep tillage and Happy seeder provided better grain yields than other tillage methods, whereas N125 kg/ha produced higher grain yield than all nitrogen levels over both years. Deep tillage had 44% greater nutrient utilization efficiency than all other tillage techniques. Compared to other tillage methods, deep tillage, and happy seeder had a 7 to 10% greater water use efficiency during both years, whereas N125 kg/ha resulted in a 53% higher WUE. Deep tillage had higher grain protein contents and N150 kg/ha nitrogen levels than other tillage techniques and nitrogen levels throughout both years.

Challenges for scaling up the technology

It is well adapted to Pakistan having annual rainfall of 400-1,150 mm and is best suited to sandy-to-sandy loam soil. Its seasonal crop water demand is 500-700 mm, and the permissible moisture depletion in the root zone is 40%. Flowering is the most vulnerable time to water scarcity, followed by yield formation. Agriculture in the Barani tract is reliant on variable rainfall, with two-thirds of it falling during the monsoon season, therefore moisture management is critical for good crop production. However, large scale use of this technology depends on soft loan and/or subsidized price of the chisel plow.

Fig. 34 Deep-tillage by using Chisel plow /Disk plow in rainfed areas

5.26 Soil Ripping in Sugarcane

Introduction

Fig. 35 Preparation for planting of sugarcane crop

Deep soil ripping is the practice of cutting and opening the soil with a tractor while driving a sub-soiling plough.

This technique can be used to decrease soil compaction caused by past management practices. Soil compaction is a problem for pastureland because it inhibits rainfall penetration, restricts puddling and evaporation, and increases surface water runoff. Furthermore, the constraint in water cycling associated with compacted soils reduces nutrient mobility, organic matter, microbial populations and activity, and vegetative cover. Deep ripping is the process of disrupting the soil under the typical cultivation layer, frequently up to 40 centimeters, without inverting the soil.

A recent Sustainable Agriculture Research and Extension (SARE) Producer Grant investigated the efficiency of a management practice known as deep soil ripping, or subsoiling, to absorb and store water on the landscape, eventually boosting water capture on rangelands.

Benefits and limitations of the technology

- Water and energy smart technology.
- For optimal yield reaction, the ripping depth must be below the traffic pan, which may require penetration of at least 30 cm.
- Moist soil is required throughout the ripping depth to decrease power requirements and point wear, as well as to achieve efficient softening.
- The availability of sufficient soil moisture conditions is the key challenge in tolerating deep ripping within the farming system. When soils get too dry, draught and fuel usage increase dramatically.
- Deep ripping of compacted soils is most likely to boost grain yields on sandy soils and where compaction has developed on top areas of the soil profile due to mechanical traffic or cattle trampling.
- Recent advancements in technology, such as ‘slotting' and deep placement equipment to simultaneously inject ameliorants at depth with ripping, may boost the financial and agronomic efficacy of this technique in controlling subsoil restrictions.
- Deep ripping is very useful for breaking through a compacted pan or separate restricting layer, allowing roots to access unrestrained soil water under this layer.

Nevertheless, deep ripping has few limitations. Deep ripping is less efficient on thick clay soils until supplemented with gypsum on waterlogged sodic soils. Deep ripping will be ineffective if additional subsurface restrictions like salinity, sodicity, or acidity are present. The advantage of deep ripping will be restricted if the soil below the depth of ripping has additional restrictions, such as acidity, weak structure from sodicity, or subsoil salinity. Although it is feasible to inject lime into acidic subterranean soil behind deep ripping tines, this is a lengthy and difficult procedure to perform on a big scale (shallow leading tine rippers are suitable for this).

Suitability of the technology

The choice of an appropriate planting method and timetable has a significant impact on crop development, maturity, and yield. Because low temperatures and moisture stress are harmful to germination and subsequent establishment, subtropical planting should take place in the spring. However, in locations where winter is harsh enough to stunt or even kill sugarcane growth, planting material may only be available in the autumn, forcing pre-winter planting. A sufficiently wet season should be chosen for planting and establishment in tropical settings, particularly if irrigation is not used. When soil moisture conditions are favorable, thorough ripping should be performed prior to cropping, with enough time provided for subsequent seedbed preparation. This is not always doable in various environments/seasons.

September planted crops often give a 25 to 35% greater yield. Sugarcane planting in Pakistan is mainly done in the autumn and spring seasons. Autumn planting has a higher yield and sugar recovery than spring planting. In fact, September planting produces lush growth that is prone to lodging. The crop looks healthy until June-July, but it is prone to lodging in July or even sooner if there are windstorms or significant rainfall. Around 26% of growers plant sugarcane in October, 45% in November, 2% in December, and 7% in February.

Adaptability rate

In Pakistan, sugarcane is a significant industrial and economic crop. It can be grown in a variety of conditions, from hot, dry environments close to the sea to cool, wet environments at higher altitudes, in tropical and subtropical regions of the world. In addition to sugar, sugarcane also yields a variety of useful byproducts, such as press mud, a rich source of organic matter and nutrients for crop growth, ethanol used as a fuel, bagasse used to make paper and chipboard, and alcohol used in the pharmaceutical business. The primary thing that can help to boost sugarcane production in the field is the grower. The majority of farmers in Pakistan are unaware of the correct techniques or procedures for growing sugarcane. Because of this, the cane production is less and its quality is also poor. To get the maximum production of sugarcane with good quality, growers must be given assistance. The adaptability rate is not high because of costly soil-ripping practices.

Impact and suitability to smallholder farmers

First, most of the farmers are unaware of current technologies and the advantages of implementing them. Second, targeted users cannot easily access certain technologies, or they cannot access them at the appropriate moment. Third, the complicated mix of issues that farmers face, such as problems with factor input allocation and the regulatory environment, restrict innovations from becoming profitable.

Success story of the technology

In controlled traffic systems soil ripping is undertaken only in the cane growth zones to clear stubbles from the previous crop and prepare the seedbed for the next sugarcane setts planting; the compacted wheel traffic zone is largely left alone. The compacted condition of the inter-row areas is thought to be insignificant in terms of cane growth and yield. There is strong evidence of increased water flow following a heavy rain event, as well as topsoil erosion due to increased compaction in wheel tracks. The excessive compaction in the inter-row zone does influence the soil's physical characteristics, which could negatively affect cane productivity and sugar yield.

Soil ripping treatments were applied to the compacted wheel track in a sugarcane production-controlled traffic system, and mill able cane and sugar yields were measured across a four-year crop cycle in terms of soil bulk density, penetration resistance, volumetric moisture content, and infiltration rates. Ripping and hilling (RH) of the wheel traffic zone increased the physical qualities of the soil in the cane rows, with advantages lasting up to four years. Breaking up the compacted soil has an effect on the cane.

Challenges for scaling up the technology

Soil ripping treatments were applied to the compacted wheel track in a sugarcane production-controlled traffic system, and millable cane and sugar yields were measured across a four-year crop cycle in terms of soil bulk density, penetration resistance, volumetric moisture content, and infiltration rates. Ripping and hilling (RH) of the wheel traffic zone increased the physical qualities of the soil in the cane rows, with advantages lasting up to four years. Breaking up the compacted soil has an effect on the cane.

Fig. 36 Soil ripping in sugarcane crop

5.27 Integrated Pest Management in Sugarcane and Other Crops

Introduction

Integrated Pest Management (IPM) is a revolutionary approach for insect pest management in sugarcane cultivation in Pakistan. Stem borers (Lepidoptera: Pyralidae), soil pests (Coleoptera: Curculionidae and Scarabaeidae), and vertebrate pesticides are the three major insect pests of sugarcane in the country.

Pesticides are harmful not only to the environment but also to human health. As a result, an alternative way of integrated pest management (IPM) is a viable methodology for controlling insect pests and protecting the environment for the benefit of human health. IPM is a practical and environmentally friendly approach to pest management. Insect pests can be managed by integration of various tactics like cultural and mechanical, growing of resistant sugarcane varieties, exploiting the potential of bio-control agents (parasitoids, predators, pathogens), modifications of the pest environment, and need-based judicious use of insecticides because no single method can manage all the pests or even a single pest under all situations. 75 percent of the farmers believe that height is a big barrier to the implementation of IPM. It has also been reported that IPM adoption is not practicable in a timely way owing to a variety of problems, including the scarcity of bio-control agents, bio-insecticides, pesticides, pheromone traps, spraying equipment, technical labor, etc.

Benefits of the technology

Integrated pest management (IPM) is a viable methodology for controlling insect pests and protecting the environment for the benefit of human health. IPM is a practical and environmentally friendly approach to pest management.

Limitations of the technology

Pesticides are costly but biocontrol agents and biopesticides are time-consuming. According to a survey, nearly 62.5% of the farmers said that the cost of IPM inputs is higher and it also needs more labor for the timely application of each technique, they also reported that only a few pest-resistant crop varieties are available in the field. In addition, the availability of technical workers is a big issue and there is a lack of technical laborers in the region (20.0%) because laborers in the villages are migrating to cities to earn more by finding jobs in construction work or by working as a salesman.

Adaptability rate

In the past many decades, only attention has been given to chemical control in Pakistan from both government and private levels. IPM and its components have received attention in recent years. Farmers apply insecticides to get fast and quick control of insect pests despite the fact that the farmers are unaware of the adverse effects of the use of pesticides. IPM is not a single pest control method rather, a series of pest management evaluations, decision-making, and application control tactics. The use of IPM needs more time, attention, and dedication. These are the reasons why the adoption of IPM is not very much preferred by the farming community.

Suitability to smallholder farmers

Based on research conducted, rice scientists of NARC in collaboration with provincial research institutes have developed IPM technology for rice crops. The technology was disseminated among the farming community on 5,000 acres in rice-growing areas of the Punjab. The farmers were enabled to identify pests and bio-control agents to make management decisions based on ecosystem analysis and utilize different options of IPM for the control of different pests. On the basis of ecosystem analysis, the use of pesticides was reduced by up to 65% in the project area with an extra benefit of Rs. 600 per acre, which amounts up to Rs. 3,000 million estimated at the country level. The additional benefits are the conservation of beneficial organisms, less environmental pollution, minimum pesticide hazards, and achievement of stability and sustainability in the rice production system. IPM practice, although environmentally friendly is not liked by the farmers. Indeed, IPM costs are higher than insecticide costs.

Success story of the technology

In view of the growing importance to achieve sustainable productivity, it is difficult to see anything other than IPM, which can prove an acceptable or affordable basis for pest control in the future. The Farmer Field School (FFS) is the best approach in implementation of IPM, which evolved from the concept that optimal learning derives from experience. The FFS integrates the domains of ecology and non-formal education to give farmers the opportunity to learn about their crop and to learn from each other.

The research findings demonstrated that the majority of respondents were unable to conduct IPM due to a lack of technical knowledge, practical abilities, and awareness about sugarcane pest identification and treatment. The findings revealed that IPM technology can help reduce pesticide use while also protecting the environment and human health. The study recommended that an understanding of integrated pest management be promoted through appropriate campaigns to overcome the blind usage of pesticides for sugarcane insect pest mitigation.

Challenges for scaling up the technology

IPM has been introduced as the best alternative for pest management in rice crops. IPM in rice helps minimize risks to the environment and human health. Nevertheless, IPM is time-consuming and requires more knowledge about pests and rice crops. There are several other challenges regarding the implementation of IPM in rice. One of the most important obstacles in the implementation of IPM is that it requires the combined efforts of the farmers within the farming community as pests can move easily from one field to another. Another major problem is its complexity and it is difficult to integrate new pest control practices to make it acceptable to the farmers. Other challenges regarding the implementation of IPM are lack of training/knowledge among the farmers and above all, IPM is labor-intensive.

Above all, government policy is also vital for the successful implementation of IPM. Government policies and actions like reducing pesticide subsidies and providing monetary support to strengthen extension, research, and technical services can be helpful in the successful implementation of IPM.

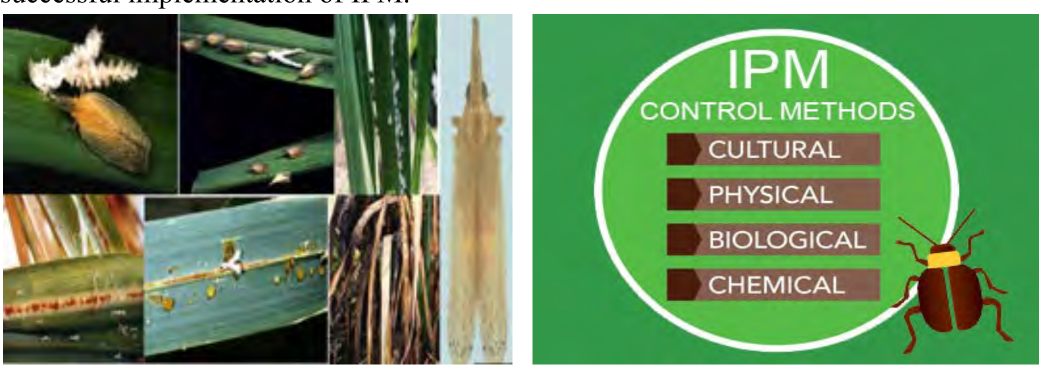

Fig. 37 Integrated pest management (IPM) of sugarcane crop

5.28 Row Planting with Proper Spacing in Sugarcane

Introduction

Sugarcane is a major industrial and economic crop in Pakistan. Pakistan's average sugar cane production is 450-500 maunds per acre, which is quite low when compared to other cane production countries. Among the agronomic parameters planting method and row spacing have a substantial impact on its productivity.

In Sindh province, farmers are using proper row spacing for sugarcane between 90 cm and 1 m. They place two budded double sets side by side in the furrows with a 2 to 3cm layer of soil. For planting one acre, around 3.2 to 4 tons of seed (80 to 100 munds) for thin cane types and 4 to 5 tons of seed (100 to 120 munds) for thick kinds are required.

Methods of sugarcane planting

- Sugarcane planting in raised beds.
- Ridge and furrow method.
- Trench method.
- Distant planting method.
- Pit planting.
- Skip furrow planting.
- Algin method of Planting.
- Bud transplanting.
- Sprouting method.

Benefits of the technology

- It is a knowledge-smart technology.
- Row spacing had a considerable impact on cane length.
- The greatest cane lengths (2.32 and 2.28 m) and the shortest cane length (2.24 m) were recorded in strips with 90 cm between double rows and 120 cm between triple rows, respectively.
- The cane width was considerably influenced by row space and planting density.
- The greatest cane diameter was measured using strips with a 60 cm single row spacing and a 90 cm double row spacing, respectively, while the smallest cane diameter was measured using strips with a 120 cm triple row spacing.
- The largest cane diameter was measured in crops planted at seeding densities of 60,000 and 75,000 setts/ha.
- The greatest cane weights (1.20 and 1.18 kg, respectively) were obtained from 90 cm spaced double row strips and 120 cm spaced triple row strips.

Autumn and Spring are two planting seasons. Fall planting begins in the first week of September and continues until mid-October in Punjab and Sindh, while planting in the NWFP occurs in October and November. Spring planting in Punjab and Sindh begins in mid-February and continues until the end of March.

Optimizing row spacing can potentially improve yields when resources such as light and water are limited. Row spacing optimization can increase yield because yield typically increases as row spacing decreases until maximum light interception and canopy closure are achieved so further decreasing row spacing increases the density-dependent competition of resources and yield declines.

Adaptability rate

For increasing sugarcane output, many planting methods have been used in Pakistan. Most farmers use conventional planting techniques, such as planting in furrows 60 to 75 cm apart, which helps increase plant population per unit area to some extent but causes issues like intercultural operations, air circulation, and light interception, all of which are crucial for good crop yield. The adaptability rate is not high, it is medium.

Suitability to smallholder farmers

This crop is very important for small land-holding farmers throughout the world. The key factors responsible for low production are the unavailability of sufficient financial resources for the farmers, drought stress, and high operational costs. Variable input prices have also an impact on the yields of small-holding farmers. The study of Thibane et al., (2023) revealed that smallholding farmers utilize a proper quantity of fertilizer with proper row spacing geometry and mechanical maintenance to increase sugarcane production.

Success story of the technology

Ehsanullah et al. (2011) conducted a field study to check the performance of sugarcane (*Saccharum officinarum* L.) grown at various row spacing and seeding densities. Three-row spacing (60 cm between single rows, 90 cm between double rows, and 120 cm between triple rows) and three seeding densities (60,000, 75,000, and 90,000 double-budded setts ha^{-1}) were used in the experiment. A seeding density of 75,000 double-budded setts/ha provided the highest number of mill-able canes m^{-2} (7.65), while a seeding density of 60,000 setts/ha produced the lowest number of mill-able canes per sq m^{-} (7.09). The highest cane length (232 cm) was attained by 90 cm double row strips, which were also equal to 120 cm triple row strips (228 cm), whilst the minimum cane length (224 cm) was seen at 60 cm single row spacing. The greatest cane yield (92.27 t/ha) was attained in strips with double rows placed 90 cm apart.

In terms of seeding density, 75,000 double-budded setts per ha gave the highest cane yield (92.54 t/ha), which was at par with 90,000 double-budded setts/ha (89.85 t/ha), while 60,000 double-budded setts ha^{-1} produced the lowest cane yield (83.68 t/ha). Cane length, cane diameter, stripped cane output, harvest index, and total sugar were all highest when sugarcane was cultivated in 90 cm separated double-row strips. The maximum number of mill-able canes, cane diameter, weight per cane, number of internodes per cane, stripped cane yield, harvest index, and total sugar output were observed with a seeding density of 75,000 double-budded sets per hectare. Sugarcane planted in 90 cm double row strips with a seed rate of 75,000 double budded setts/ha yielded the greatest net return of Rs. 67,046 per ha and the highest benefit-cost ratio of 1.63.

Challenges for scaling up the technology

Wider row spacing enhanced soil water content, especially during periods of low rainfall, increasing the plant-accessible water pool available for transpiration. Regardless, plant-available water was high in any row spacing design and seldom fell below 50% of field capacity. Consistently, high plant-available moisture content suggests that transpiration may increase significantly without affecting sugarcane development due to water scarcity. If sugarcane water usage rose in an effort to maximize yields in relation to water resources, wider row spacing would be the most suitable row spacing. Therefore, by making use of this substantial plant available water pool, sugarcane breeding for insensitive stomata and increased photosynthetic capacity have the potential to create types that can generate higher yields.

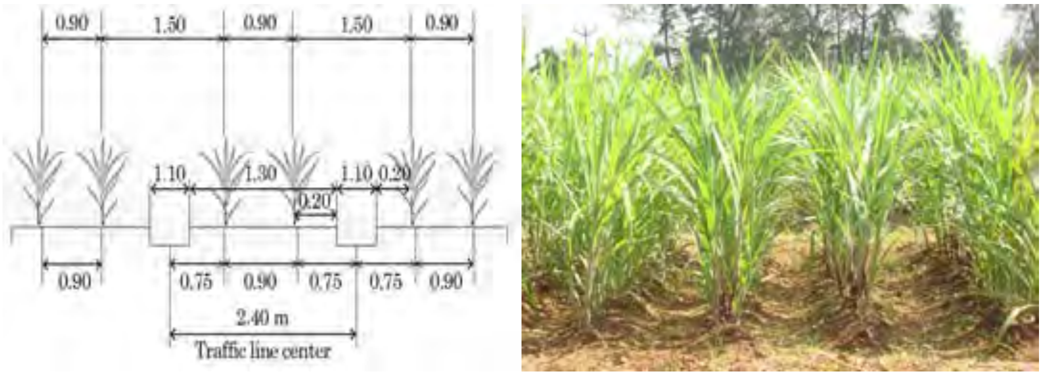

Fig. 38 Row planting with proper spacing in sugarcane cultivation

5.29 Biopesticides

Introduction

Biopesticides, also known as biological pesticides are compounds derived from natural creatures or substances that are used to control or reduce agricultural pests, weeds, and disease-causing agents through particular biological effects. There are several definitions of what constitutes a biopesticides.

Microorganisms such as bacteria, viruses, fungi, protozoa, and entomopathogenic nematodes can be used to make microbial pesticides, which are biopesticides that target specific plant pests. Botanical biopesticides (plant extracts) are also a kind of pesticide. Toxic metabolites, illness, competition for food and space, and other methods of action are some of the ways that pests are controlled.

The misuse or overuse of pesticides by farmers is prevailing due to insufficient knowledge about the risks of occupational exposure (Rashid et al., 2022). Pesticides are being used in Pakistan at a rate of around 130,000 metric tons per year, with approximately 90% applied to cotton, rice, sugarcane, fruits, and vegetables. The wide use of pesticides in agriculture has contaminated the high value-added commodities like rice, cotton, vegetables, and fruits, due to which the prices of these commodities have shrunken in the international market. Recently biopesticides have received much attention as an alternative to chemical pesticides (Haq et al., 2019).

Benefits of the technology

- Biopesticides are less hazardous to people and are better for the environment.
- There is less chance of developing pest resistance.

- The biodegradability of biopesticides minimizes the danger of environmental exposure.
- The microbes used in the preparation of these bio-pesticides are non-toxic and non-pathogenic to wildlife, humans, and other non-organisms.
- These are highly specific to a single group of insect pests and thus have no adverse impact on other beneficial living organisms.
- Their residues are harmless and can be used at harvest and applied microbes may establish in pest populations.

Limitations of the technology:

- It is a knowledge-smart technology.
- They have a limited shelf life.
- They only effectively manage a certain subset of pests since they are only effective against the target species.
- Farmers can find them unclear and challenging to implement.
- The cost of manufacture is significant, and regulatory body approval might take a very long period.

Suitability of the technology

Biopesticides have recently attracted a lot of interest as a viable alternative to chemical pesticides. These are live microorganisms (viruses, bacteria, fungus, protozoa, or nematodes) or the metabolites they create. They are used as pesticides in the form of sprays, dusts, liquid drenches, liquid concentrates, wettable powders, or granules. Biopesticides have a pesticidal component that comes from naturally occurring sources such as plants, animals, viruses, bacteria, and minerals. These organic products offer protection against pests, insects and diseases, which are transmitted from the soil. Microbial pesticides such as viruses, fungi, nematodes, and bacteria are the sources of biopesticides, which are a component of IPM (integrated pest management) and by their use; plants develop resistance against insects, pests, and diseases.

Adaptability rate

The bioactive substances are essentially non-toxic and non-pathogenic to non-target species, communities, and humans. They have a small region of toxic activity, are mainly specific to a single genus or species of insect pests, and do not directly impact beneficial insects (predators, parasites, parasitoids, pollinators) in treated areas. They may be used in conjunction with synthetic chemical insecticides since the microbial product is not destroyed in most situations, and their residues have no detrimental effects on people or other animals, therefore microbial insecticides can be applied around harvesting time. Pathogenic microorganisms can grow and established in a pest population or its environment and offer pest control generation after generation or season. They promote root and plant development while also increasing production by encouraging beneficial soil microorganisms.

Suitability to smallholder farmers

Advanced research and development in the field of biopesticide applications considerably reduces environmental pollution caused by chemical synthetic insecticide residues and increases agricultural sustainability. With the introduction of biopesticides, a great number of products have been registered and marketed, some of which have dominated the agro-market. The development of biopesticides has pushed the replacement of chemical pesticides in pest management. The present status and progress of biopesticides with an emphasis on enhancing action spectra, replacing chemical pesticides, its function in integrated pest management, and correct use of botanical and semi-chemical pest control.

Success story of the technology

Microbes and their bio-products/metabolites have been studied as pesticides since the discovery of Bacillus thuringiensis (BT) in 1902. Scientists discovered its deadly impact on insects in 1950. Since then, there have been numerous ups and downs in the study of microbial pesticide formulation. Because of their rapid and beneficial outcomes, chemical pesticides gained popularity among farming communities at the time. This issue had a noticeable impact on the commercial usage of microbial biopesticides in agriculture.

Challenges for scaling up the technology

Pakistan is an agricultural nation that is currently experiencing several issues as a result of environmental degradation and climate change. Biopesticides are used to manage a range of weeds, diseases, and insect pests. Biopesticides compete with or stimulate plant host resistance. A disease or insect pest's growth, nutrition, development, or reproduction can be regulated biochemically. Plants become resistant to insect pests as a result of biopesticides use. Microbial pesticides such as viruses, fungi, nematodes, and bacteria are the sources of biopesticides,

Fig. 39. Harmonization of regulatory requirements for maximum residue limits and biopesticides in Pakistan

5.30 Agroforestry Wind Barriers

Introduction

Agroforestry windbreaks are barriers that can slow down wind speed and are created by growing trees, whether they are natural or artificial. A windbreak needs to be 2.5 feet height or higher to be effective. Use trees, bushes, and tall perennial or annual plants (like switch grass or sunflowers) that will grow tall enough to give the appropriate wind shadow to create a windbreak (Asae and Siddoway, 1976). The use of windbreaks in agriculture is not a new concept. The Scottish Parliament urged the planting of tree belts to protect agricultural production as early as the mid-1400s (Droze, 1977). Shelterbelts have been used extensively throughout the world to provide wind protection since their inception (Caborn 1971).

Benefits of the technology:

- It is a carbon and knowledge-smart technology.
- Wind erosion of soil is controlled.
- Protect livestock and crops.
- Catch runoff water and nutrients.
- Enhance irrigation efficiency.
- Filter and minimize dust to aid with odor control.
- Keep constructions safe (homes, outbuildings, roads).

Limitations of the technology

- Need specialized tree or shrub management.
- May harbor harmful crop pests, e.g., insects & weed.
- A barrier made entirely of vegetation is not possible.
- Finally, yet important, the length of the wind's path through the barrier lengthens as the angle of the approaching wind becomes more oblique to the barrier (less perpendicular).
- This is the same outcome as widening the barrier, which also alters the windbreak's effect on wind flow by increasing density.

Suitability of the technology

The several aspects of this technology are as follows:

- Windbreak height.
- Windbreak density.
- Windbreak orientation.
- Windbreak length.
- Windbreak width.
- Windbreak continuity.

Adaptability rate

In an era of global overpopulation, the agroforestry system can step in as a novel technique that can protect agricultural sustainability, provide a source of income, provide environmental advantages, and contribute to household food security. Adoption of long-term agroforestry methods, on the other hand, necessitates a comprehension of both farmers' personal qualities and perceived statuses, which is a challenging process to anticipate, evaluate, and depict. To that purpose, it is critical to comprehend and identify the most important elements driving agroforestry adoption. Agroforestry is a sustainable and eco-friendly practice that aids farmers in meeting their financial needs. In Pakistan, about 1.8 million people depend on agroforestry goods and services for their livelihood (Ahmad et al. 2021).

Suitability to smallholder farmers

Windbreaks offer societal benefits on a bigger scale, both locally and regionally. Landowners benefit from erosion reductions, which also lower off-site erosion expenditures. Windbreaks might help with climate adaptation in the future and, in some situations, they might lessen the financial consequences of change. Windbreaks on a farm or in a community can lower energy costs, increase crop yields, keep livestock healthy and robust, and provide specialty items (nuts, fruits, or beautiful flowers) or wood products (firewood, posts, or lumber).

Success story of the technology

In the sheltered zones, windbreaks improve the environment by lowering wind speed. They should be a crucial component of all vegetable production systems because they maximize the ecological benefits of ecosystem variety while offering numerous direct benefits to the grower. In Pakistan, there is more demand for wood than is produced annually. 60% of all timber output and 90% of all fuelwood production occurs on farmlands. Farm forestry in this instance largely satisfies the need for timber.

Agroforestry is an integrated system of sustainable agriculture that coordinates the management of crops, trees, and livestock on the same piece of land. The benefits of agroforestry have been supported by numerous studies. A key element of an agroforestry system is that tree planting encourages food diversity and security while reducing poverty, as it becomes a source of income. Agroforestry typically has the potential to preserve biodiversity and offer rural residents' alternate means of survival. Agroforestry techniques are used all around the world to gain social, ecological, and economic advantages.

Challenges for scaling up the technology

In Pakistan, about 68 million hectares of area is semi-arid which receives less than 300 mm of rainfall annually. A quarter of the country's land is almost appropriate for intensive farming, although there are issues with salinity and sodicity, water and wind erosion, water logging and flooding, and the loss of organic matter in this area (Abbas et al., 2021). Surface winds have an impact on crop growth and development, animal health, and the overall farm or ranch environment. Windbreaks and shelterbelts are wind-reducing barriers. They are usually made up of trees and shrubs, but they can also be perennial or annual crops, grasses, wooden fences, or other materials. They are used to protect crops and livestock, control erosion and provide wildlife habitat, supply tree products, and improve landscape aesthetics.

Fig. 40 Agroforestry windbreak for crop protection

5.31 Manure Management or Composting in Animals

Introduction

Composting is a natural process that occurs under controlled settings in which air, temperature, and moisture content are regulated for the growth and multiplication of microorganisms and the conversion of organic material into a more useable form of organic matter.

Pakistan's economy is built on agriculture as 67% of country's population lives in rural regions and is mostly dependent on agriculture. Pakistan's soils are deficient in organic matter and have a low carbon and nitrogen ratio and the total fertility state is insufficient to sustain higher agricultural yields. Compost is a good alternate approach for increasing soil organic matter content. Cow manure, often known as animal waste, can exist as a liquid, slurry, or solid substance. By dispersing it over fields, it is used to enrich the soils without polluting the water or enriching the soils with excessive amounts of nutrients. Nutrient management also includes manure management.

Focus of the technology

To protect the environment and ensure sustainable agriculture, build resilient rural regions, and enhance productive farming, it is vital to pursue the appropriate use and development of animal waste management as compost or organic manure. Livestock manure, crop residues, green manure, filter cake, and silage, slaughterhouse waste, other solid and liquid-based materials, compost, and biogas compost, etc. are sources of organic matter that can be used to improve soil organic matter in Pakistani soils.

Benefits and limitations of the technology

Composting provides benefits over other agriculture waste management practices such as landfilling agricultural waste. Composting is an environmentally beneficial and cost-effective agricultural waste disposal practice. The quality and type of the livestock's feed, as well as their digestive health, which controls how much N and C is accessible and can be converted to gaseous products, determine the composition of manure. The other danger of animal excrement is contamination and damage to the ecosystem. Only in Karachi, garbage quantity is about 6,600 tons per day; roughly, 33% of this is poorly handled and ends up in drains, waterways, or is indiscriminately thrown in open spaces in air and water, causing environmental degradation. According to the Food and Agriculture Organization of the United Nations, Asia has the fastest-growing livestock sector, followed by Latin America and the Caribbean. As a result, animal waste production in these areas is increasing day by day. The government of Pakistan has implemented a scheme to improve livestock production by increasing the number of heads.

The environment where manure is stored controls bacterial development. Warm temperatures boost microbial activity in liquid systems, which increase both N_2O and CH_4 production. Rainfall can increase the formation of CH_4 in solid systems, with wet regions having higher CH_4 emission rates than arid ones. If sufficient nitrate is present in the nitrified manure, rain may encourage the denitrification process, releasing N_2.

Adaptability rate

In Pakistan, livestock is the second-largest agricultural sector, generating goods such as meat, milk, wool, bones, hair, fat, skin, and hides. The increase in animal numbers is proof that Pakistan's primary livestock sectors are becoming more prosperous. Pakistan's soils are lacking in organic matter, having less than the 1.29% carbon threshold required for sufficient soil. The carbon concentration of Pakistani soils ranges from 0.52 to 1.38% for different soil types, with the majority having less than 1% carbon. The low organic matter content of Pakistani soils has been linked to a variety of factors, including climate, soil, usage or non-use of mineral fertilizers, farmers' difficult economic circumstances, intense ploughing, etc.

Suitability to smallholder farmers

For Pakistan's smallholder sector, manure is a crucial source of nutrients for crop production. It helps farmers to use less commercial fertilizer, increasing crop and pasture production's profit margin. Compared to chemical-based fertilizers, the nutrients in organic manures are released more gradually and are retained in the soil for a longer time, ensuring a long-lasting benefit. Manures, also known as farmyard manure, have traditionally been of primary importance to Pakistani farmers, and these have only undergone minimal farmer manipulation to enhance the quality of the compost. Manures are typically not given high attention by most farmers, and they are often stored in a careless manner without any thought to their potential as a fertilizer. In rural households, manure is typically stored in heaps that are exposed to the sun, wind, and rain, which can result in significant nutrient losses.

Success story of the technology

It has been reported that integrated nutrient management enhances the yield of rice crops and improves soil quality. Study reveals that integrated nutrient management improves soil carbon stock, microbial biomass carbon, and soil fertility. The integrated use of F.Y.M and chemical fertilizer gave a significantly higher yield 9.86 v/s 9.41 Mg ha^{-1} than those with chemical fertilizer alone. It can be concluded that the application of chemical/organic manures alone may not be sustainable for rice-rice roping systems (Paramesh, 2023). Due to farmers' lack of knowledge regarding the utility of animal dung as a fertilizer and fuel, poor manure management techniques are widespread on many farms around the world. Manure is frequently dumped in piles, slurries, or lagoons, which can result in considerable methane emissions, environmental damage, adverse health effects, and the loss of important nutrients that could enrich the soil. Composting has simplified the process of decomposing animal manure under regulated circumstances. Although composting is costly and time-consuming, it is a better choice for restoring soil fertility and keeping the environment clean, healthy, and friendly.

Challenges for scaling up the technology

Without adequate manure management procedures, the increasing animal numbers required to meet this demand will result in an equal rise in emissions and other problems associated with manure collection, storage, treatment, and utilization. While there are currently integrated manure management strategies, many farmers lack the information they need to improve manure management or are hampered by institutional, technical, and socioeconomic barriers that prohibit them from implementing new procedures.

Fig. 41 Use of compost developed from farmyard manure

5.32 Controlled Sheds in Animals and Poultry

Introduction

Successful management is essential for a chicken farm and animals raring. Poor management practices will lead to poor output. In a control shed of a poultry farm, everything is automated, making management of the entire population very simple and easy. The controller is one of the most crucial components of a poultry farm with a control shed in Pakistan. On a control farm, practically a controller controls everything. It is possible to run anything with an electrical power source, including cooling pads, brooders, feeding lines, and shed fans. The success of the entire farm will depend on the controller's performance. Furthermore, since the majority of poultry farms are situated outside cities, we would be able to fix our controller if there is any malfunction.

Focus of the technology

- Replacing low-producing poultry with high-producing breeds.
- Efficient utilization of feeds while feeding poultry.
- Improving poultry manure management.
- Installation of solar powering systems for climate-smart poultry production.

Benefits of the technology

Poultry farming in controlled environments has revolutionized the poultry sector in Pakistan and is quickly gaining popularity with grill producers because of the following key benefits:

- The temperature remains constant throughout the clock, creating an ideal habitat for the broilers.
- When compared to a normal farm, the temperature in a controlled environment farm may be reduced by 10°C to 15°C, making the atmosphere more comfortable for birds.
- In conventional farming, grill production nearly halts in the summer, with just four flocks available, however in controlled environment farming, 6-7 flocks may be grown.

- Mortality has been reduced to 2 to 3% in controlled environment farms, compared to 10% in traditional farms.
- In a controlled environment farm, just one worker is needed during the day and one at night to care for a flock of 35,000 birds. In a normal farm, 6-8 people are needed to handle such a flock.
- A broiler flock in a controlled environment farm is ready for market in 37 days, compared to 45 days on a conventional farm.
- The feed conversion ratio (FCR) on a conventional farm is 2 to 2.2 (3 to 3.3 kg feed to gain 1.5 kg weight), however the FCR in a controlled environment farm is 1.8 (2.8 kg feed to gain 1.5 kg weight).

Suitability of the technology

There are certain things that need to be managed by owners, like hygiene and vaccinations. To operate a successful chicken business, all of these factors are required. The temperature, feeding, and drinking systems are automatically managed and kept under the trained staff supervision in a controlled environment. Following the marketing of broilers at around the age of six weeks, the broiler house is given 15 days to prepare for the arrival of the next flock. The new flock is properly cleaned, washed, whitewashed, disinfected, and fumigated using the required chemicals before it arrives. At the facility, rigorous biosecurity regulations are upheld during operation.

Adaptability rate

Poultry is one of the vibrant sectors of Pakistan's agriculture industry and about 1.5 million people are employed in this sector. It contributes about 4.81% to the growth of agriculture and 9.84% to the growth of livestock. A total of 19% of the nation's total meat output comes from poultry. Currently, more than 200 billion rupees have been invested in this sector and this industry has a growth rate of 8–10% per year, which shows its inherent potential (Pakistan Poultry Farming, July 18, 2019).

Suitability to smallholder farmers

The progressive rise in white meat consumption in Pakistan over the past few years can be attributed to the general public's rising health consciousness. Grill meat is the least expensive type of animal protein accessible in Pakistan. Compared to other sources of animal protein, grill chickens are raised in a shorter amount of time. The market's rising desire for white meat has turned it into a successful economic enterprise for smallholder farmers and women. The techniques like keeping high producing chicken breeds, efficient feeding management and poultry manure management (composting) can be economically viable for larger poultry enterprises or cooperative facilities followed by small farmers throughout the country.

Success story of the technology

With a population of 35,000 birds, the Controlled Shed Poultry Farm requires a capital expenditure estimated at Rs. 19.2 million for building, buying machinery, and equipment. Additionally, working money in the amount of Rs. 5.7 million is required, which will be utilized to buy day-old chicks and other inputs like feed, immunizations, etc. The anticipated cost of the project is Rs. 24.9 million. According to industry sources, in

Pakistan about 5,000 environmental control houses were constructed, of which now there are 2,500 in working condition and the majority of these i.e., 75% (1,875), are in Punjab, while the remaining i.e., 25% (625) are in other provinces (Pakistan Poultry farming, July 18, 2019).

At the national level, poultry meat accounts for 35% of total meat production in the country, which is about 1,657 thousand tones out of a total of 4,708 thousand tones. With an annual output of 1,163 million broilers, Pakistan has risen to the 11th largest poultry producer in the world.

Challenges for scaling up the technology

The biggest issue in animal and poultry production is heat stress. Being a tropical nation, the summertime temperature may exceed 40°C making it unsuitable for raising poultry. Weather that is hot and muggy, combined with inadequate management techniques, causes flock mortality to rise, growth to slow, and production of chicken to become unprofitable. A controlled environment for animals and poultry farms can overcome this critical summer situation. These farms when equipped with highly mechanized systems of automatic chain feeding and nipple drinking systems make the environment quite conducive for poultry production by getting continuous production.

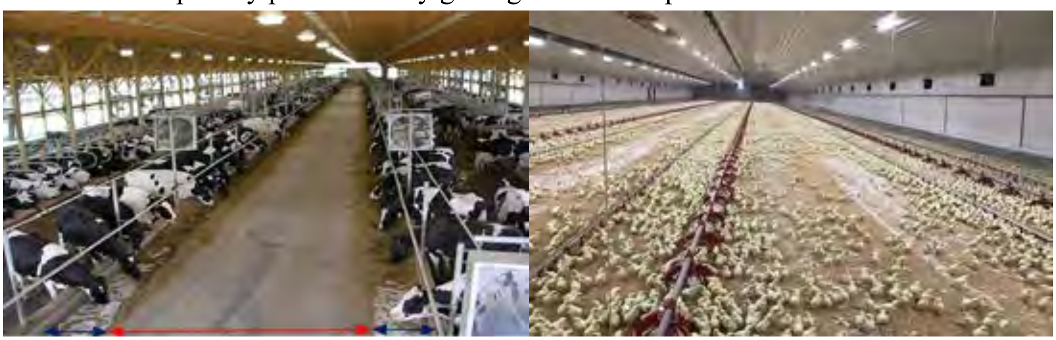

Fig. 42 Commercialized controlled sheds used for rearing livestock and poultry

5.33 Poultry Manure for Composting

Introduction

Fig. 43. Poultry manure production

Pakistani soils are deficient in organic matter. The physical characteristics of the soil and all associated chemical processes in the soil have deteriorated due to a lack of organic matter. Organic matter can be supplied to the soils in a variety of ways, such as Farm Yard Manure (FYM), compost, green manure, rice husk, and chicken manure. These techniques are all encouraged to increase soil productivity. Superior organic fertilizers include chicken manure, pigeon manure, goose manure, quail manure, and other poultry manure. The nitrogen, phosphorus, and potassium contents of chicken manure are 1.63%, 1.54%, and 0.085%, respectively. Before use, the chicken manure must be thoroughly decomposed by a decomposition agent, which inactivates the parasite and its eggs, as well as infectious bacteria.

Benefits and limitations of the technology

It has been reported that integrated use nutrients i.e., full dose of chemical fertilizers + chicken dung 10 t ha^{-1} gives more nitrogen, phosphorus, and potassium concentrations in maize shoots and roots. So, farmers are advised to use mineral fertilizer in conjunction with chicken waste products to obtain nutrient-rich corn feed (Fiyyaz et al., 2021). It indicates that poultry manure might perhaps replace chemical fertilizers. The use of chicken manure for agricultural production might address Pakistan's current fertilizer shortage issue in addition to an effective waste management strategy.

Use of poultry manure during warm seasons is not advised since it quickly mineralizes in soil and generates a lot of heat. By using efficient best management practices, detrimental effects from the land application of chicken manure may be avoided. Air, water, and soil are only a few of the environmental compartments that are affected by emissions from intensive chicken rising. Manure and other waste products, such as chicken litter are frequently produced in greater quantities than are necessary to fertilize the nearby agricultural area. The quality of the land and water may be seriously harmed as a result of overuse

Adaptability rate

The use of poultry manure as fertilizer in agricultural production was found to be more economical than by using the chemical fertilizers. According to farmers, their main objective was to increase soil fertility by using the poultry manure or to give justification for utilization of chicken manure for agriculture production. They also reported that use of chicken manure is also beneficial supplement to rice soils. Farmers selected developing poultry business and inexpensive pricing of poultry manure as assuring the availability as second and third options, respectively. Because there is competition among the farms, chicken manure, which is generated on a huge scale in commercial poultry farms, is sold for a low price. Farmers placed understanding the range of bio-fertilizers as the fourth factor.

Suitability to smallholder farmers

Poultry farming is one of the most effective techniques of animal husbandry since it allows for the use of a wide range of feedstock including agricultural and home leftovers as well as wastes from the food processing industry. For communities in rural locations across the world, particularly in developing nations, it offers a reliable protein source in addition to food and nutritional stability. The best strategy to control nutrients in the soil is to combine carbon-based manures such as poultry manure, cow dung, crop leftovers, and green manure crops with mineral fertilizer. This technique leads to increased soil fertility, soil conservation, and reduced environmental contamination. Extensive use of multiple nutritional sources proved critical for increased crop growth and sustainable agriculture. When mineral fertilizers combined with diverse organic components, rice, and wheat growth increased for smallholder farmers and women farms. When FYM (10 t/ha) was treated together with chemical amendments, physical characteristics such as bulk density, porosity, void ratio, water permeability, and hydraulic conductivity were noticeably improved, leading to increased yields of rice and wheat in sodic soil.

Challenges for scaling up the technology

It is getting harder to control the waste generated as the poultry business grows on a worldwide scale. It now contains pollutants and a method for enhancing the impact of greenhouse gases. The globalization of the chicken industry generates a large volume of solid waste. On-premises near poultry farms, almost 90% of the waste produced by birds is routinely excreted. Therefore, an adequate understanding of the composition and effects of manure as a chicken by-product is necessary for optimal environmental management. In order to efficiently build, implement, and administer fundamental waste management systems on farms suited for the broad use of manure to prevent its potentially detrimental effects on wildlife, the environment, and humans, this knowledge must be put into practice.

Fig. 44 Poultry dung compost used as organic fertilizer

5.34 Improved Breeds in Cattle and Poultry for Reduced GHG Emission

Introduction

Greenhouse gases (GHGs) are defined as gases that absorb and emit thermal infrared radiation, trapping heat in the atmosphere. The greenhouse effect is a phenomenon that traps solar radiation and absorbs infrared radiation. This phenomenon was named after greenhouses, which frequently maintain life during the colder months by absorbing radiant energy from the sun and preserving it inside a glass enclosure. As a result, the greenhouse effect prevents our planet from being as cold as it would be without an atmosphere.

When compared to the production of other livestock products, poultry farming has been determined to be more environmentally friendly, but it still has an impact on environmental issues such as eutrophication, acidification, and global warming. The production and transportation of feed account for over 70% of the potential warming effect of poultry systems, whereas the management of manure accounts for roughly 40% and 60% of the potential eutrophication and acidification, respectively. Methane is the primary source of greenhouse gas emissions from cattle, and it is mostly created via belching, which occurs naturally when cattle digest feed. Additionally, emissions arise during the excretion and storage of manure.

Benefits of the technology

Poultry farming should be more environmentally friendly; however, it still has an impact on environmental issues such as eutrophication, acidification, and global warming. Cattle are a good source of CH_4 emissions but with the improved breed of cattle and poultry, GHG emissions will be minimized.

Limitations of the technology

- It is difficult to measure methane emissions.
- Low methane emission heritability has a moderate heritability, and annual genetic increases are probably less than 1%.
- More productivity improvements are achieved when selection is based on other factors.
- It may not be economically advantageous for smaller businesses to embrace the strategy.
- When stocking rates rise because of improved feed conversion efficiency, methane emissions might also go up overall.

Challenges for scaling up the technology

In some circumstances, increasing animal wellbeing may increase productivity, which would benefit farmers and the livestock industry, for instance by reducing social stress, enhancing health, or increasing offspring survival. Decision-makers should firmly promote the "win-win-win" techniques that improve sustainability with relation to societal, environmental, and economic problems of cattle production. For instance, methods for lowering direct CH_4 emissions will improve energy availability, which will be advantageous for the energy balance, which can be crucial in high-producing animals.

Fig. 45 Controlled sheds for cattle and poultry production

6. Conclusions and Recommendations

Pakistan is basically an agricultural country and thus, agriculture sustainability under the situation of climate vulnerability is a vital issue for food and nutrition security for the people of the country. In the context of the identification and compilation of Climate Smart Agriculture (CSA) technologies that are in use or in the development process, an Inventory of CSA Technologies and Practices has been prepared. In the inventory, we have composed 34 promising CSA technologies which are either newly developed or age-old technologies. Not all the technologies are farmers friendly or recommendable for use by the farmers. Although many technologies look very sound and highly science-based, still the farmers do not accept those technologies either due to a lack of awareness or due to farmers' financial inability to avail this opportunity.

The CSA technologies as identified fall into five categories: weather smart, carbon smart, nutrient smart, energy smart, and knowledge smart. It can also be classified into five groups: (i) improved crop varieties (drought tolerant wheat varieties, pest-resistant onion & cotton varieties, short duration rice & and maize varieties, etc.), soil and crop management (mulching, leaf color chart, sensor-based nitrogen management, green manuring, organic & biofertilizers, crop calendar, legume-based cropping system, residue management, legume-based crop rotation, DSR, SRI, etc.), (iii) pest management (biopesticides, IPM, etc.), (iv) irrigation management (solar powered drip irrigation, AWD, etc.), and (v) farm mechanization (laser land leveler, mechanical transplanter, raised bed planter, LLP, zero tillage, combine harvester, etc.). The approach of Conservation Agriculture (CA) which includes reduced tillage, residue retention, and legume-based crop rotation has significant value in the perspective of improved and sustainable soil fertility, carbon sequestration, reduction of greenhouse gas emissions, and crop productivity.

CSA inventory will be helpful in scaling up promising technologies in the different agro-ecologies of Pakistan. Thus, future food and nutrition security depends on how effectively and maximally the climate change effects we would be able to address through technological innovations and practices and on top of government strategies and implementation for agriculture sustainability in the face of vulnerable climate situations.

Recommendations

Choose the right technology

- To assess the applicability of a technology and/or combination of technologies, it is essential to have a comprehensive image of the field.
- A review of present procedures, the degree of automation, and the accessibility of services is required.
- Field tests should be used to create and validate specially adapted technology and farmers should be included in the process.

Create a network of support

- The deployment of climate-smart technology should be supported by a comprehensive strategy that meets all criteria, such as enhancing channels for information dissemination and service delivery.

- Learning coalitions or communities of practice that can support one another should exist.
- To increase farmers' access to information and expertise, a smart extension service system should be created.

Enhance the delivery system

- To be more effective in promoting and distributing crop varieties and technologies that are climate-smart in Pakistan, the Department of Agricultural Extension and Agricultural Research Institutes should be strengthened.
- In order to help farmers practice climate-wise agriculture, the government should set up community-based service centers.
- To assist climate-smart agriculture, a platform that brings together researchers, farmers, the commercial sector, and academics will be helpful.

Make the private sector-friendly atmosphere

- The government must establish a supportive atmosphere so that private businesses may produce equipment with unique designs and offer after-sales support.
- Moreover, the ability of the extension service to cooperate with the commercial sector and educate farmers about climate-smart technology should be improved.

Encourage the use of private service providers

- The majority of smallholder farmers lack the financial resources to invest in climate-smart agriculture equipment.
- Farmers should be motivated to rent machines from recruiting centers set up by the private sector. Farmers' cooperatives should also be encouraged to open job centers.
- However, such cooperatives should be administered in accordance with corporate principles, i.e., with a clear line of demarcation between stockholders and management employees, all of whom must answer for their actions.

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