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Singhadurbar Plaza, Kathmandu

Climate-Smart Agriculture Technologies and Practices in Nepal

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

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SAARC

SAARC Agriculture Centre (SAC)

South Asian Association for Regional Cooperation (SAARC)

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Inventory of Climate-Smart Agriculture (CSA) Technologies and Practices in Nepal 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 Nepal' contains the climate-smart agriculture (CSA) technologies and practices of Nepal produced as an output of the inventory of CSA technologies conducted by the National Focal Point of C-SUCSeS project of Nepal and the associates working under the Nepal Agricultural Research Council (NARC). 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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Nepal Agricultural Research Council

Executive Director

Foreword

Nepalese government has realized the impact of climate change on its agricultural systems. However, it is late to accelerate climate change adaptation research in this country. Nepal is one of the most vulnerable countries to climate change, and it has already witnessed significant changes in the patterns of temperature and precipitation in recent years. Most of the model-based projections indicate an increase in the mean annual temperature resulting in more extreme weather events. This will have a negative impact on food security, people's livelihoods, and the overall economy of the country. At this critical juncture, I feel that the Nepal Agricultural Research Council (NARC) has a critical role in providing sufficient alternate adaptation options to our farmers.

NARC has developed many improved varieties/breeds, crops, and livestock production packages, such as zero tillage, and special production structures such as plastic houses that can be classified as climate-smart agriculture (CSA) technologies. This has contributed to the country's efforts to promote climate change adaptation practices.

NARC has received support from different international agencies while working on the climate change adaptation front. However, our efforts are insufficient, and the rate at which farmers are adopting CSA technologies is not satisfactory. The need for accelerated up-scaling of these technologies has been realized. In this context, the publication of this evidence-based summary of 40 CSA technologies practiced in Nepal is a milestone in itself.

I appreciate the effort of my colleagues at NARC and outside who are contributing to climate change adaptation and mitigation. I would like to thank Dr. Tika Ram Chapagain and his team for preparing the manuscript "Climate-Smart Agriculture Technologies and Practices in Nepal." We are grateful to Dr. Ganga Dutta Acharya and Mr. Kinzang Gyeltshen for assisting in preparing this document and also for funding this work through the SAARC Agriculture Centre (SAC), Dhaka, under the C-SUCSeS project. We look forward to collaborating with more international communities to reduce the risk of climate change and improve people's quality of life.

Dr. Dhruba Raj Bhattarai

Preface

Nepal has witnessed negative consequences of climate change in different dimensions of livelihood. Agriculture, the major source of livelihood, is directly under the threat of climate change. It is predicted that the rate of warming in Nepal is faster than the global average. Certainly, it would have severe negative consequences for agricultural production in the future. To increase the adaptability of our farming systems, agricultural scientists have developed many technologies for different agro-ecological zones. These technologies collectively considered as Climate Smart Agriculture (CSA) technologies can mitigate emissions, build resilience to climate change, and contribute to sustained productivity. We have tried to present the best-known and adaptable CSA technologies through this work.

Agricultural practices can play roles in increasing as well as reducing emissions. The use of chemical fertilizers, flooded rice cultivation, energy use in irrigation, tillage, and enteric fermentation from ruminant animals contribute to greenhouse gas deposition in the atmosphere. At the same time, carbon sequestration by plants, especially fruit/fodder trees, and nitrogen and carbon deposition in soil helps reduce emissions. CSA technologies contribute to climate change mitigation without compromising the productivity of our agricultural systems. However, the adoption of these technologies on a wider scale is far from reality. To increase the adoption of these technologies, we have to present them with the research evidence. This inventory report is an attempt in this direction.

This inventory report starts with a brief introduction to Nepal, its agriculture, and the impact of climate change on agriculture. It also provides the background of government policies on agriculture and climate change. To provide a better understanding of CSA, its major components have been discussed. The government of Nepal has shown a keen interest in climate change adaptation. Therefore, the CSA priorities of the Nepal government and the role of different institutions working in climate-resilient agriculture have also been included. We have listed important CSA technologies practiced in Nepal and prioritized them based on the participants' preference ranking held in provincial workshops.

The major focus of this report is an evidence-based description of CSA technologies practiced in Nepal. The CSA technologies have been described under six CSA smart categories: i) Weather smart, ii) Water smart, iii) Energy smart, iv) Nutrient smart, v) Knowledge smart, and vi) Carbon smart. Adoption of climate-resilient crop varieties by our farmers increases the sustainability of the farming system and reduces the risk of crop failure due to climate change. Energy-efficient tillage practices, irrigation management schemes along with nutrient management help reduce greenhouse gas emissions. Crop diversity through intercropping/mixed cropping and fish or livestock integration helps increase food and nutritional security.

We are hopeful that the information collected in this report will provide a clear picture of CSA technologies available in Nepal with evidence. It will help analyze research gap and pave the way for further research and dissemination.

Tika Ram Chapagain | Tika Bahadur Karki
Pradeep Shah | Ganga Dutta Acharya

Acknowledgment

We would like to acknowledge all the scholars whose works were compiled to prepare this inventory report. It was possible due to the hard work of our colleagues working at the Nepal Agricultural Research Council, national and international organizations, and scholars from various universities and independent researchers. Most of the information was gathered from anonymous researchers who have contributed through annual reports. We are thankful to NARC management for providing official authority to complete this work. Some people significantly contributed to the preparation of this report. The report could not have been accomplished without the generous help of many colleagues working under NARC. Our special thanks go to Dr. Deepak Bhandari, then Executive Director, NARC, for his encouragement and Dr. Dhurb Raj Bhattarai, ED, NARC for the foreword to this report.

We are grateful to the International Fund for Agricultural Development (IFAD) for financial support through the South Asian Association for Regional Cooperation Agriculture Centre (SAC) under the Consortium for Scaling-Up Climate Smart Agriculture in South Asia (C-SUCSeS) project. We would like to thank Dr. Md. Baktear Hossain, Director, SAC, Mr. Kinzang Gyeltshen, Regional Programme Coordinator, and Dr. Ganga Dutta Acharya, SPS, SAC for their constant cooperation and encouragement throughout the project implementation and preparation of this report.

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Abbreviations

ADB	Asian Development Bank
ADS	Agricultural Development Strategy
AFU	Agriculture and Forestry University
AGD	Agronomy Division
AGDP	Agriculture Gross Domestic Product
AIRC	Agriculture Implement Research Center
AKC	Agriculture Knowledge Center
AWD	Alternate Wetting and Drying
B:C ratio	Benefit Cost Ratio
CBS	Central Bureau of Statistics
CBO	Community Based Organizations
CBSP	Community Based Seed Production Program
CCAFS	Climate Change, Agriculture and Food Security
CEAPRED	The Center for Environment and Agricultural Policy Research, Extension and Development
CGIAR	Consultative Group on International Agricultural Research
CH_4	Methane
CIAT	International Center for Tropical Agriculture
CIMMYT	The International Maize and Wheat Improvement Center
C: N ratio	Carbon Nitrogen ratio
CSA	Climate Smart Agriculture
CSAIP	Climate Smart Agriculture Investment Plan
C-SUCSeS	Consortium for Scaling-up Climate Smart Agriculture in South Asia
CSV	Climate Smart Village
CT	Conventional Tillage
DHM	Department of Hydrology and Meteorology
DLS	Department of Livestock Services
DoAR	Directorate of Agricultural Research
DDSR	Dry Direct Seeded Rice
DSR	Direct Seeded Rice
FAO	Food and Agriculture Organization
FYM	Farm Yard Manure
GDP	Gross Domestic Product
GHG	Green House Gas
GoN	Government of Nepal
ICIMOD	The International Centre for Integrated Mountain Development
INGO	International Non-Government Organization
INM	Integrated Nutrient Management
IPCC	Intergovernmental Panel on Climate Change
IFPRI	International Food Policy Research Institute
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
LCC	Leaf Color Chart
LIBIRD	Local Initiatives for Biodiversity, Research and Development

LLL	Laser Land Leveler
m.a.s.l	Meter above sea level
MoALD	Ministry of Agriculture and Livestock Development
MoAF	Ministry of Agriculture and Forests
MoE	Ministry of Education
MoFE	Ministry of Forest and Environment
NABGRC	National Animal Breeding and Genetics Research Center
NAERC	National Agricultural Environment Research Centre
NARC	Nepal Agricultural Research Council
NARS	National Agricultural Research System
NCCP	National Climate Change Policy
NCRP	National Cattle Research Program
NGOs	Non-Governmental Organizations
NPC	National Planning Commission
NMRP	National Maize Research Program
NPK	Nitrogen Phosphorus Potassium
NRRP	National Rice Research Program
NRs	Nepalese Rupees
NWRP	National Wheat Research Program
OC	Organic Carbon
PMAMP	Prime minister Agriculture Modernization Project
PPCR	Pilot Program for Climate Resilience
RARSN	Regional Agricultural Research Station Nepalgunj
RARSP	Regional Agricultural Research Station Parwanipur
RARST	Regional Agricultural Research Station Tarahara
RD	Recommended Dose
RDF	Recommended Dose of Fertilizer
REED	Reducing Emission from Deforestation and Forests Degradation
SAARC	South Asian Association for Regional Cooperation
SAC	SAARC Agriculture Centre
SALT	Sloping Agriculture Land Technology
SRI	System of Rice Intensification
SSNM	Site Specific Nutrient Management
SSMP	Sustainable Soil Management Program
t/ha	Ton per Hectare
TU	Tribhuwan University
SWI	System of Wheat Intensification
UN	United Nation
USD	United States Dollar
VDC	Village Development Committee
WFP	World Food Program
WB	World Bank
ZT	Zero Tillage

1. Introduction

Nepal is a highly diversified country located between India and China. The country is 885 km long from east to west and 193 km wide from north to south, with a total area of 147,516 square km. There is a large variation in topography which encompasses the world's deepest gorge 'Kali-Gandaki' to the highest point on the earth, Mount Everest at 8,848.86m. Nepal is the 10th in position in terms of flowering plant diversity in Asia and 31st on a world scale (MoFSC 2014). The population of Nepal is 2, 91, 92, 480 out of which the Male and Female population is 48.96 and 51.04%, respectively (CBS 2021). A new constitution was promulgated in 2015 which politically divides the country into seven provinces and 753 municipalities.

Nepal is diverse in terms of landscape, topography, altitude, and temperature. The Terai, Hills, and Mountain areas form the three agroecological zones of the country, covering its agricultural land (World Bank 2011). With slight variations in altitude range, Nepal is divided into five physiographic regions (Table 1, Fig. 1). Due to its flat lands, rivers, and fertile soil, agriculture is concentrated in the Terai area (NPC and WFP 2019). Nearly 60% of Nepali people are engaged in agriculture and the sector contributed about 26% of the national GDP in 2022. Food production has increased and the global hunger index (GHI) has improved in recent years, though the hills and mountains of three provinces viz Gandaki, Karnali, and Sudurpaschim are largely food-insufficient (NPC and WFP 2019).

Rice, wheat, and maize are the main cereal crops for food security in Nepal. Crop production is mainly based on rainfall and more than 80% of precipitation occurs during monsoon season. The country is extremely vulnerable to geological and climate-related risks because of its weak geology, steep topography, extremely high rainfall, and its location in an active seismic zone (NPC and WFP 2019). The country has developed and implemented various agricultural adaptation strategies to offset the negative impact of climate change. Nevertheless, there are chances of increasing the frequency of extreme events in the future.

Table 1. Farming systems, cropland, and demographic distribution based on physiographic regions of Nepal.

Regions	**Dominant farming systems**	**Value chain**	**Crop land**	**Population (2021)**
High Mountains (>5,000m)	Agropastoral: Sheep and yak, potato/buckwheat-barley systems	Yak, seed potato	225,400 ha (7%)	1,778,104 (6.73%)
Middle Mountains (3,000-5,000m)	Swidden agriculture: pastures Upland cereal crops: Maize, millet, potato, wheat, mustard with cattle; buffalo and goats	Tea, cardamom, sericulture, apiculture dairy, meat		
	Horticultural-led farming systems: Citrus, apple, tea, cardamom, ginger, seed potato vegetable seeds, and vegetable	Apple, seed potato, tea, cardamom, and vegetable seeds		

Regions	Dominant farming systems	Value chain	Crop land	Population (2021)
Hills (1,000-3,000 m)	Upland crops-dominated mixed farming systems; Maize, millet, wheat in terraces and potato in gentle slopes with buffalo, cattle, and goats, Agroforestry	Off-season vegetables, vegetable seeds, citrus, ginger, meat, dairy, apiculture, sericulture	1,223,000 ha (27%)	11,748,548 (40.25%)
Lower hills (Churia /Siwalik 500-1,000m)	Agricultural rainfed production, primarily low-yield fallow agriculture, and agroforestry, with different crops including upland rice, maize, vegetables and mustard, forage, and fodder	Tropical fruits and vegetables, export-quality rice, sugarcane		
Terai southern flat plains (below 500 m)	Paddy-dominated systems: Rice-wheat, Rice-mustard/lentil Rice-vegetables with cattle, buffalo, and goats	Tropical fruits and vegetables, export-quality rice, sugarcane, meat, dairy	1,771,000 ha (55%)	15,665,828 (53.66%)
Total			**3,220,000 ha**	**29,192,480**

Source: Adapted from WB 2021, MoFE 2021, CBS 2021)

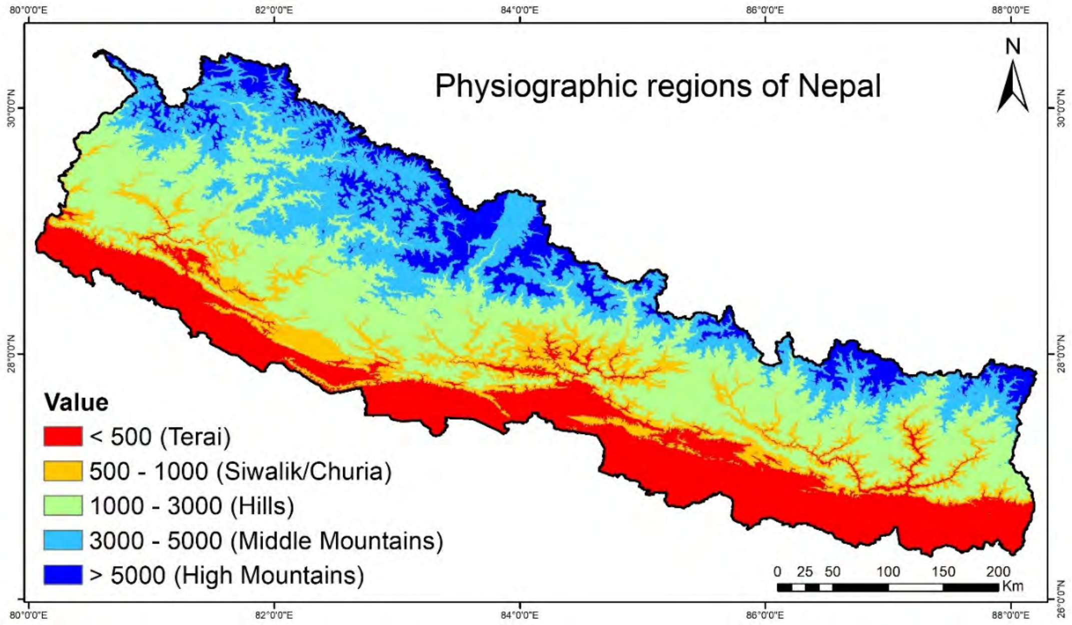

Fig. 1. Physiographic regions of Nepal

1.1 Nepalese agriculture and food system

Agriculture is the main source of livelihood in Nepal. About 3,091,000 hectares (21%) of its total land are being utilized for agricultural purposes (MoALD 2020). Rice is the major crop which is cultivated in 1,458,915 hectares of land followed by maize and wheat. Vegetables are grown throughout the country. Two-thirds of the population is engaged in agriculture, contributing 26% share to the national GDP (NPC and WFP 2019). The livestock sector contributes about 13 and 27 percent to GDP and AGDP, respectively (DLS 2020). Thus, the agriculture sector plays a major role in promoting equitable economic growth and the reduction of poverty in Nepal (WBG 2022).

Nepal has made significant improvements in food security in recent years, however, about 29% of urban households and 38% of rural households have food insecurity (NPC and WFP 2019). Regional imbalance is another pertinent challenge as Karnali and Sudurpaschim provinces have more food insecurity as compared to the other parts of the country.

Moreover, the sustainability of the achievements is in question particularly due to the increasing vulnerability of the agriculture sector to climate change (MoFE 2021a). Earning a livelihood from agriculture is always uncertain due to the diverse topography with small land holdings, insufficient irrigation facilities, low levels of income, limited institutional capacity, and a high dependence on climate-sensitive natural resources (Regmi and Adhikari 2007).

Food imports have increased fourfold from 2011 to 2018, and this indicates weak domestic agriculture in terms of the country's food security (NPC and WFP 2019). Climate risks including drought, floods, and unpredictable rainfall are responsible for 10 - 30 percent loss in the agriculture sector due to the loss of crops, livestock, and fisheries (MoFE 2021c). It is estimated that drought is responsible for 38.9% loss of agriculture productivity in Nepal (WFP 2021). Only 33 percent of areas of irrigated land have irrigation facilities throughout the year (MoFE 2021b). The direct economic cost of climate vulnerability in the agriculture sector in 2020 was 1.5 - 2 percent of GDP (GoN 2021).

Livestock is an integral part of Nepalese farming systems. The majority of people who engaged in agriculture also undertake livestock farming (FAO 2005). Livestock and poultry provide meat, dairy products, eggs and wool, and they are the main sources of organic fertilizer for crop production (NPC and WFP 2019). Climate change is also impacting negatively to the sustainability of the livestock production system with serious implications on food, employment, and income. Some of the climate consequences on animal husbandry include pasture degradation, reduced fodder productivity, increased transboundary parasites and diseases, heat stress, altered reproductive behavior, and losses and damages from extreme events (WBG 2022).

1.2 Climate change and its impact in Nepal

Millions of people around the world face threats to their ability to access food due to climate change (IPCC 2014). Nepal ranks at the fourth most vulnerable country in the Global Climate Risk Index 2019 (German Watch 2019), which clearly indicates the upcoming challenges. Nepal has been facing environmental challenges such as species' ranges are expanding to higher elevations; glaciers are melting; and the frequency of precipitation extremes is rising due to the climate change (WBG and ADB 2021).

Under the highest emission scenario, Nepal is predicted to warm by 1.2°C to 4.2°C by the 2080s compared to the baseline period of 1986-2005 (WBG and ADB 2021). This clearly indicates that the rate of warming in Nepal is faster than the global average and certainly it will have many consequences in the future. Asian Development Bank predicts that by 2050, Nepal could lose 2.2% of its annual GDP as a result of climate change (Ahmed and Suphachalasai 2014). Over the course of the 21st century, it is predicted that a number of natural hazards, including drought, heatwaves, river flooding, and glacial lake outburst flooding, would become more severe, potentially raising the risk of disaster and endangering human lives (WBG and ADB 2021). Some of the extreme climatic events are listed in Table 2 below.

Table 2. Extreme climate indices trend in Nepal

Extreme climate indices	**Trend pattern/regions**
Number of rainy days	Increasing significantly, mainly in the northwestern districts and trend are insignificant in other districts
Very wet days	Decreasing significantly, mainly in the northern districts and trends are insignificant in other districts.
Extremely wet days	
Consecutive wet days	Increasing significantly in the northern districts of Karnali, central part of Gandaki and Koshi Province, however, the trend is insignificant.
Consecutive dry days	Decreasing significantly, mainly in the northwestern districts and trends are insignificant in other districts.
Warm days	Increasing significantly in majority of the districts
Warm nights	Increasing significantly in majority of the districts
Warm spell duration	Increasing in majority of the districts
Cool days	Decreasing in majority of the districts
Cool nights	Increasing in the northwestern significantly and decreasing in the southeast significantly
Cold spell duration	Increasing significantly only in the FWDR districts and trends are insignificant in other districts

Modified and adapted from DHM 2017, and MoFE 2021a

Nepal is vulnerable to climate-related calamities due to its diverse topography and social inequity (WFP 2021). Active seismic zones and the intense impact of monsoon rains further exacerbate climate risk in Nepal (MoFE 2021a). The country regularly receives floods, drought, air pollution, and heat stress (WFP 2021, WBG 2022).

Nepal is among the countries which has the least share on global greenhouse gas emission. Out of 48 million tonnes of carbon dioxide equivalent ($MtCO_2e$) released in atmosphere in 2019 (Climate Watch 2019), Nepal contributes only 0.1% of global GHG emissions (WB 2021). The primary sources of emissions are agriculture (54%) and energy (28%) (Climate Watch 2019). In the agriculture sector, livestock (76% including manure) and rice production (14%) activities have higher share in GHG emissions. Other sources are crop residues and burning (4%), cultivation in organic soils (3%), and fertilizer (3%) (CIAT; World Bank; CCAFS and LI-BIRD 2017).

1.3 Government policies in relation to agriculture and climate change

Nepal has initiated deliberate actions to address the challenges of climate change. Nepal's fundamental national policies demonstrate a deep understanding of the importance of boosting production, building resilience, and reducing GHG emissions (CSAIP Wordbank). Nepal has focused on identification and implementation of good agricultural practices, creating livelihood opportunities and capacity building to address food security threatened by Climate change (MoE 2010; MoE 2011; MoAD 2015). The Agricultural Development Strategy-ADS (2015-2035) aims to promote green technologies and reduce carbon emissions.

Recently, Nepal has prepared a climate-smart agriculture investment plan (CSAIP) with priorities and schemes of investment. The objective of this plan is to identify interventions and policies to support the development of a resilient, productive, and low-carbon agriculture sector focusing on four representative provinces of Nepal. Table 3 presents some policies and strategies adopted by the Government of Nepal to tackle the climate change crisis.

Table 3. Selected national policies on agriculture and climate change

National Climate Change Poilcy, 2019	☐ NCCP has provided strategic working policies for 12 different sectors including agriculture and food security ☐ Study and research on the effects of climate change and integration of results into decision-making process ☐ Mitigate adverse impacts of climate change, utilize opportunities and improve livelihood through climate friendly development ☐ At least 80% of the total climate change fund channeled to local level
Local Adaptation Plan for Action Framework, 2012	☐ Localized climate change adaptation and integration of adaptation into development planning processes
Climate Change Budget Code, 2013	☐ 11 criteria of relevance in climate budget coding ☐ Climate budget coding; categorised programmes as directly beneficial, indirectly beneficial and neutral to climate change adaptation
Reducing Emission from Deforestation and Forests Degradation (REED) Strategy, 2016	☐ Aimed at strengthening the resilience of forest ecosystems for emission reductions and increased environmental, social and economic benefits through improved policies, measures and institutions with enhanced stakeholder capacity, capability and inclusiveness ☐ Process on harnessing REED+ Readiness Emission Reduction Program
Nationally Determined Contribution (NDC), 2016	☐ Reduce climate induced hazards and disasters through mitigation and adaptation actions
National Adaptation Plan (on the process)	☐ Identifying medium and long-term adaptation needs of the country taking 2017-2030 as a medium term and 2017-2050 as a long-term ☐ Integrating climate change adaptation into policies, plans and prgrammes
Agriculture Development Strategy (ADS), 2015-2035	☐ Long-term agriculture development vision and plan ☐ Integration of climate change adaptation and resilience development in the sector

	☐ Includes research and knowledge generation on climate change such as research on stress-tolerant crop varieties, breeds of livestock and fish and development of climate-resilient agriculture.
The Fourteenth Plan 2016/17-2018/19	☐ Envisages developing productivity and competitive capacity of agriculture sector; achieving self-reliance on basic food production and harnessing potential comparative benefits of local crops; reducing agricultural dependency of the workforce by attracting them to non-agricultural services and industries, reducing negative impacts of climate change and disasters, and expanding environment-friendly agriculture technology and research and knowledge generation on climate change.
The Fifteenth Plan (2019/20-2023/24)	Key strategies to tackle climate change include: ☐ Improving and enhancing necessary policies and institutional structures at federal, provincial, and local levels for climate change management. ☐ Implementing national, provincial, and local adaptation plans to reduce the vulnerability of communities. ☐ Adopting the concept of green development and promoting clean energy to mitigate climate change. ☐ Advocating at the international level for easy access to climate finance and distributing any potential benefits to provincial, local, and community levels. ☐ Conduction research and capacity-building activities in the field of climate change.

1.4 Key indicators (Smartness) of CSA

Various approaches to classification of CSA technologies are available. Grouping technologies based on their contribution to CSA pillars, we can better categorize them into 6 different smartness categories (Fig. 2). This approach is more realistic and easier to communicate, though a single technology may fall into different groups.

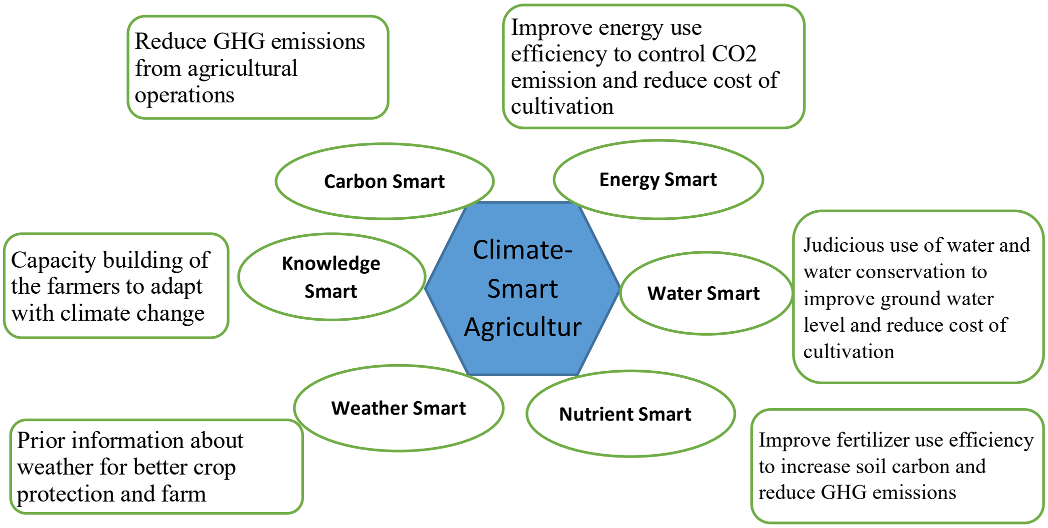

Fig. 2. Key indicators of climate-smart agriculture (Pal et al. 2019)

1.5 CSA in Nepal: Priorities and institutional effort

The second NDC promises to promote the CSA practice in crop and livestock production in Nepal (WBG 2022). It has set a target of establishing 200 climate-smart villages along with 500 climate smart farms by 2030 (NDC 2020). There are growing opportunities to invest in low-carbon and climate-resilient solutions. Across the sectors, there is increased demand for cleaner solutions, particularly where costs have declined over the last decade. In addition to hydropower, this includes solar energy, improved waste management, climate-smart agriculture, and green buildings (WBG 2022). Agricultural practices, those rely on indigenous and local knowledge are more useful in solving diverse climatic challenges in a sustainable way while contributing to food security, nature conservation, and resilience (IPCC 2019). The CSAIP has defined the role of three different tiers of government in implementation of CSA practices in Nepal (WBG 2021). It has also prioritized the CSA options for different agriculture sectors (Table 4a).

Table 4a. CSA technologies for Terai crop production system

S. N.	CSA technologies
1	System of Rice Intensification (SRI) with alternative wet and dry irrigation system
2	Good irrigation practices (gravitational and pressurized irrigation, new irrigation system to use surface and ground water, irrigation combined with optimized fertilizer application)
3	Laser land-leveling to increase water-use efficiency and reduce weed infestations
4	Relay cropping of pulses and oilseeds in rice fields for catching residual moisture
5	Zero tillage of wheat and direct sowing of rice to reduce fuel consumption and costs of production; System of Wheat Intensification (SWI)
6	Land pooling and terrace improvement for efficient mechanization
7	Precision use of chemical fertilizers and management of farmyard manure, green manures, and crop residues for mulching
8	Promotion of boro (winter) rice and winter maize
9	Drought and flood tolerant varieties of crops to increase resilience
10	Varietal improvement of niche products such as linseed, mustard, soybean, and aromatic rice

Adapted from WBG 2021 CSAIP Nepal

Table 4b. CSA technologies for hill and mountain crop production systems

S. N.	CSA technologies
1	SRI in river basin lowlands
2	Good irrigation practices for gravitational and pressurized irrigation, rainwater and snow harvesting, drip and solar based irrigation etc.
3	Soil and irrigation management through increased soil organic matters
4	Laser land-leveling in terraced areas to reduce soil erosion
5	Sloping agriculture land technology (SALT) with integrating cereal crops
6	Cover crop plantation, legume integration in maize crop, strip crop plantation using shade-loving plants such as ginger and turmeric in maize field

S. N.	CSA technologies
7	Mulching to reduce evapotranspiration and weed infestations
8	Protection from flash floods and soil erosion through bioengineering and transplantation of tree saplings and forage plants, and protecting stream banks through gabion wire, check dam, plantation
9	Drought-tolerant varieties of crops and deep rooted crop species to increase resilience

Adapted from WBG 2021 CSAIP Nepal

1.5.1 Institutional involvement in CSA development and promotion

Many national and international organizations are contributing to CSA identification, prioritization, development, dissemination and capacity building in Nepal (Table 5). Ministry of Forest and Environment (MoFE) is the focal ministry for climate-change related issues in Nepal. It mainly coordinates with international agencies (mainly UN) for different conventions. MoFE has played key role in developing key climate change policies. Though MoFE is the main institution for climate change, it coordinates with Ministry of Agriculture and Livestock Development (MoALD) for implementing climate change related agricultural activities.

The MoALD is the main national entity responsible for formulating policies and programs that reduce the agriculture sector's vulnerability to climate change and increase food production. The Food Security and Food Technology Division of MoALD is the national focal point for agriculture and climate change. Prime Minister Agriculture Modernization Project (PM-AMP) under MoALD is also undertaking CSA-related activities in different parts of the country.

Nepal Agriculture Research Council (NARC) develops location-specific technologies considering indigenous knowledge, traditional practices, and local resources under the overarching consideration of the country's agroecological diversity. NAARC in institutional partnership, and collaboration with the farmers, community-based organizations, and non-governmental organizations (NGOs) engages in developing contextual farming technologies particularly suitable for the marginal areas.

Table 5. Institutional engagement for CSA development and promotion in Nepal

Sl. No.	Institutions/project	Activities
1	MoALD/PMAMP	Policy formulation and implementation Promotion of CSA options
2	NARC in collaboration with PPCR, AFASI, UNEP/GEF, SDC/Helevetas, IRRI CIMMYT, and LI-BIRD	Agro-met advisory services (climate change adaptation), IPM and Organic farming, Traditional crop diverisification to adapt climate change, Gender sensitive and climate adaptive technology, Mechanization on rice-lentil system, Heat stress resilient maize and climate resilient wheat
3	Agriculture Ministry of Lumbini and Gandaki Province	Climate smart village (CSV) implementation

Sl. No.	Institutions/project	Activities
4	CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), New Delhi, India Local Initiatives for Biodiversity, Research and Development (LI-BIRD)	CSA project through which they identified champion CSA practices for three AEZs and developed CSA scale-up strategies, CSV implementation
5	Practical Action	- Promoting environmentally sustainable farming approaches, - ensuring better access to renewable energy for agricultural use, - providing climate information services and better business linkages. - advising government bodies on making agriculture policies and assistance more sustainable and - demonstrating to private sector business that agro-ecological farming approaches can be profitable as well as planet-friendly.
6	The International Centre for Integrated Mountain Development (ICIMOD) and Environment and Agricultural Policy Research (CEAPRED)	Environment and Agricultural Policy Research (CEAPRED) are piloting a Resilient Mountain Village concept with strong emphasis on CSA for hill systems.

National Agricultural Environment Research Centre (NAERC) of NARC is the main centre responsible for coordinating and conducting research on climate change and CSA. The national commodity research programs (rice, wheat, maize, and potato) have also mainstreamed the climate change issues in their operations and have developed many crop varieties resilient to climate change, and tolerant to diseases and pests. National Agricultural Engineering Centre and Agriculture Implement Research Centre have been developing and verifying different energy, water smart and drudgery reduction CSA technologies in farmers' field.

The Provincial agricultural ministries and agriculture sections at municipalities/rural municipalities carry out variety of agricultural development activities with due consideration of the environment and human welfare. The constitution of Nepal 2015 authorises Provincial and Local governments for working on biodiversity conservation, environment protection, and agricultural development. Agriculture Ministry under the Provincial Government has district level agriculture and livestock offices (Agriculture knowledge Center and Veterinary Hospital and Livestock Expert Service Center) to implement CSA activities at farmers' level. Some Provinces have been implementing CSA activities. At the local level, human resource capacity is limited, and they need technical and financial support to effectively implement CSA options.

1.6 CSA Inventory of Nepal

The C-SUCSeS project aims to support farmers in the SAARC region through the promotion of CSA technologies. This inventory of CSA technologies of Nepal has been prepared as part of this project. The purpose of this document is to briefly introduce all CSA technologies available for the farmers of Nepal.

1.6.1 CSA technologies practiced in Nepal

Many CSA technologies are practiced by the farmers of Nepal. The technologies are quite context specific. Similarly, there are few CSA technologies that fulfill all three pillars and the GESI consideration and some of them show smartness in different categories. Farm practices qualify as CSA if any one of the criteria is positively influenced and none of the others are negatively affected or a very nominal negative effect is observed (Thapa et al 2015).

The list below includes the agricultural technologies that practiced in Nepal and are qualified as CSA practice (Table 6).

Table 6. A list of majot CSA technologies practiced in Nepal

Sl. No.	**CSA technologies**	**Smartness categories**
1	Climate resilient crop varieties	Weather smart, knowledge smart
2	Weather based crop insurance	Weather smart
3	Protected cultivation for vegetable production	Weather smart
4	Climate smart housing for livestock	Weather smart
5	Stress tolerant breed	Weather smart
6	Laser land leveler (LLL)	Water smart
7	Direct seeded rice	Water smart
8	System of rice intensification	Water smart
9	Drip irrigation	Water smart
10	Sprinkler irrigation	Water smart
11	Alternate wetting and drying irrigation in rice field	Water smart
12	Rainwater harvesting	Water smart
13	Pond water depth for fish farming	Water smart, Energy smart
14	Mulching	Water smart, Weather smart
15	Raised bed planting	Water smart
16	Cover crops method	Water smart
17	Conservation furrow	Water smart
18	Sloping agriculture land technology (SALT) with integrating cereal crops	Water smart, Nutrient smart, Carbon smart
19	Laser land leveling	Water smart
20	Irrigation management	Water smart
21	Conservation furrow	Water smart

Sl. No.	CSA technologies	Smartness categories
22	Furrow irrigation	Water smart
23	Zero tillage	Energy smart
24	Minimum tillage	Energy smart
25	Solar pump	Energy smart
26	Solar dryer	Energy smart
27	Zero-energy storage	Energy smart
28	Use of leaf colour chart (LCC)	Nutrient smart
29	Site specific nutrient management	Nutrient smart
30	Improved compost	Nutrient smart
31	Improvement of farmyard manure	Nutrient smart
32	Crop diversification	Nutrient smart
33	Conservation agriculture	Nutrient smart, Carbon smart
34	Biochar	Nutrient smart
35	Permanent bed planting	Nutrient smart
36	Jhol mal (plant/urine based liquid form of fertilizer)	Nutrient smart
37	Integrated nutrient management	Nutrient smart
38	Green manuring	Nutrient smart
39	Sowing/planting time adjustment	Knowledge smart
40	Home garden	Knowledge smart
41	Integrated fish farming	Knowledge smart
42	Rice cum duck farming	Knowledge smart
43	Contingent crop planning	Knowledge smart
44	Agro-met advisory	Knowledge smart
45	Livestock and fishery as diversification strategy	Knowledge smart
46	Integrated pest management	Knowledge smart
47	Concentrate feeding for livestock	Carbon smart
48	Fodder management	Carbon smart
50	Agro-forestry	Carbon smart
51	Scientific management of grazing land (rotational etc.)	Carbon smart

1.6.2 CSA technologies under C-SUCSeS project

Under this project, stakeholder workshops were organized in Karnali, Lumbini, Gandaki, and Madhesh provinces to identify promising CSA options for different cropping systems. Based on the focus group discussion, some important CSA technologies were identified for different cropping systems at the provincial level (Table 7). At the same time, individual ranking of the selected technologies for different provinces was made (Table 8).

Table 7. Selection of CSA options for different cropping systems

Rice-Rice system	Rice-Wheat system	Rainfed Mix system	Upland Mix system
Laser land leveling	Climate resilient crop varieties (flood, drought, heat, cold tolerant and early maturing varieties)	Agro-met advisory	Scientific management of grazing land
Submergence tolerant rice varieties	Laser land leveling	Mixed farming	FYM improvement
Integrated plant nutrient management	Integrated nutrient management	Irrigation management (Rain water harvesting, micro irrigation)	Integrated plant nutrient management
Community seed bank	Irrigation management (solar pump)	Integration of legumes	Integration of legume crops
Planting time adjustment	Agro-met advisory	Integrated nutrient management	Rain water harvesting
	Community seed bank	Mulching	Rain water harvesting
	Direct seeded rice	Agro-forestry	Range land management
	Mulching	Community seed bank	FYM improvement
	Zero-tillage	Climate resilient crop varieties (drought, heat, cold tolerant)	Community seed bank
	Alternate wetting and drying	Agriculture insurance	Fodder management
	Inclusion of legumes in cropping systems		

Table 8. CSA options prioritized for different provinces

Grading	Karnali	Lumbini	Gandaki	Madhesh
1	Insect pest tolerant varieties	Climate resilient crop varieties	Alternate wetting and drying irrigation in rice field	Direct seeded rice
	Climate resilient crop varieties	Planting time adjustment	Direct seeded rice	Laser land leveling
	Rainwater harvesting	Agro-met advisory	Use of mulching	Zero tillage
	Sprinkler irrigation	Integrated nutrient management	Insect and pest tolerant varieties	Green manuring

Grading	Karnali	Lumbini	Gandaki	Madhesh
2	Integrated nutrient management	Use of mulching	Drought and flood tolerant varieties	Solar pump
	Community seed bank	Agricultural insurance	Agro-met advisory	Drought and flood tolerant varieties
	Drip irrigation	Inter cropping with legumes	Fodder management	Agro-met advisory
	Direct seeded rice	Green manuring	Laser land leveling	Integrated nutrient management
3	Agro-met advisory	Rainwater harvesting	Agricultural insurance	Alternate wetting and drying irrigation in rice field
	Conservation agriculture	Sprinkler irrigation	Drip irrigation	Community seed bank
	Use of mulching	Drip irrigation	Rainwater harvesting	Use of mulching
	Intercropping with legumes	Community seed bank	Zero tillage	System of rice intensification
4	Solar pump	Mixed cropping	Planting time adjustment	Drip irrigation and sprinkler irrigation
	Agro-forestry	System of rice intensification	Solar pump	Inter cropping with legumes
	Integrated pest management	Integrated pest management	Community seed bank	Flood tolerant varieties
	System of rice intensification	Alternate wetting and drying irrigation in rice field	Agro-forestry	Planting time adjustment
5	Site specific nutrient management	Laser land leveling	minimum tillage	Mixed cropping
	Agricultural insurance	Fodder management	Integrated nutrient management	Integrated pest management
	Mixed cropping	Solar pump	Inter cropping with legumes	Raised bed planting
	Planting time adjustment	Zero tillage	Green manuring	Conservation agriculture

2. Purpose of CSA Inventory

In developing countries, particularly in South Asia, most of the important crops will experience a drastic yield decline due to climate change (IFPRI 2009). Therefore, like other member states of SAARC, Nepal also has been working on developing climate-resilient crop varieties, selecting adaptable breeds of livestock, improved husbandry systems, and sustainable crop intensification. NARC, Universities, I/NGOs, CBOs, etc. are involved in technology development and dissemination. The rate of up-scaling is slower than anticipated for a number of reasons, including the lack of an evidence-based comprehensive bundle of technologies.

The scientific basis of each CSA technology is provided by this CSA inventory, giving development workers more confidence to choose them for a particular agroecological zone or circumstance. It provides a clear insight into the researchers' findings with respect to particular CSA technology. Likewise, it is helpful for policymakers and donor agencies to prioritize their resources.

3. Methodology of CSA Inventory

The preparation of the climate-smart agriculture technologies inventory report started with the listing of CSA technologies practiced in Nepal through reviewing relevant documents. We finalized the list of CSA technologies that are practiced in Nepal through focus group discussions with experts, farmers, and other stakeholders. Later, based on available information on the internet, desktop reviews, and expert consultation, we explained the individual technologies to a considerable extent.

4. Concept and Pillars of CSA

In the late 20th century, the debate on climate change and its impact on agriculture has gained momentum. After the establishment of the IPCC in 1988, global action on the policy formulations to mitigate climate change was initiated. In 2009, for the first time the concept of CSA surfaced in the global debate (Lipper and Zilberman 2018). The concept of CSA became widespread when FAO released a conceptual paper on "Climate-Smart" Agriculture, Policies, Practices and Financing for Food Security, Adaptation and Mitigation" during the 2010 Hague Conference on Agriculture, Food Security, and Climate Change (FAO 2010). CSA aims to improve food security, help communities adapt to climate change, and contribute to climate change mitigation by adopting appropriate practices, developing enabling policies and institutions, and mobilizing needed finances (FAO 2013). Climate smart agriculture has been put forth as a comprehensive strategy to adapt to the effects of climate change without compromising food security (Van Wijk et al. 2020). It integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. It mainly focuses on three aspects (Fig. 3),

CSA does not imply that every practice in every location would deliver the maximum positive results for each of the three objectives. Rather, the CSA approach seeks to reduce trade-offs and promote synergies by taking these objectives into consideration when stakeholders make decisions at all levels, from local to global (FAO 2017).

Three pillars of CSA

Many studies have been conducted to assess agricultural inventions and classify them as CSA technologies.

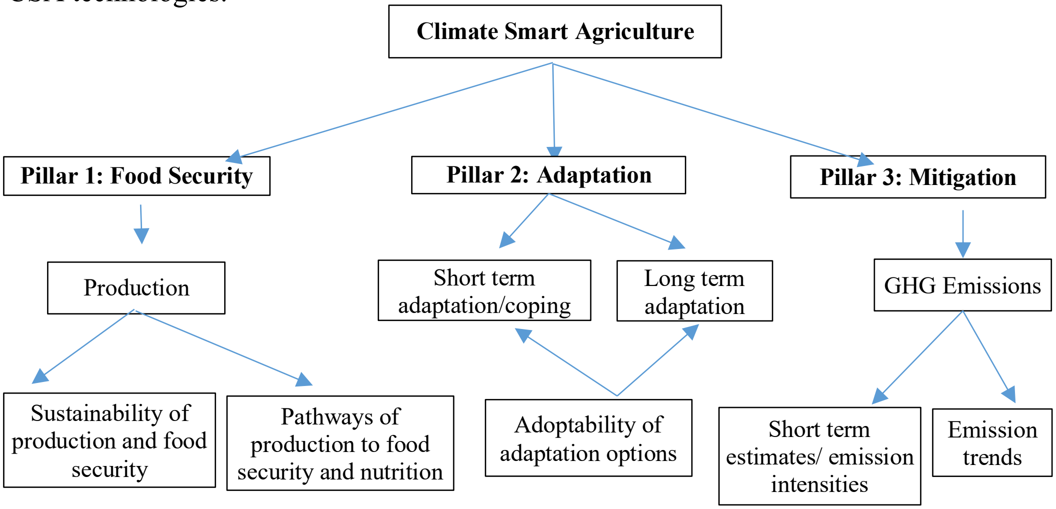

Fig. 3. Pillars of CSA

5. Brief description of Individual Technology

5.1 Weather smart CSA technologies

5.1.1 Climate resilient crop varieties

Among the important options for climate change adaptation is the development and adoption of stress-tolerant crop varieties. Nepal Agricultural Research Council has developed climate-resilient varieties of crops. Many governments, I/NGOs, and private sectors are involved in the dissemination and adoption of these varieties at the farmers' level.

Drought tolerant rice varieties

Rice is a major cereal crop and staple food of Nepal and ranks first in terms of area (1.47 million ha) and production (5.62 million ton) with the productivity of 3.81 t/ha (MoALD 2022). In Nepal about 49% of the land under rice cultivation is rainfed (Tiwari et al. 2019) and one-third (29%) of rice area (450 thousand ha) suffers from frequent droughts (Gumma et al. 2012; SARPOD 2012). Drought directly affects rice production at different stages of its growth and is largely responsible for yield losses (Aryal et al. 2021). Moreover, rising temperature and rainfall variability resulted in many regions of Nepal to be more drought prone areas (Khatiwada and Pandey 2019). Nepal Agricultural Research Council has developed drought-tolerant rice varieties to reduce the adverse impact of drought in rice production. National Rice Research Program under NARC and the International Rice Research Institute (IRRI) collaborated to develop drought-tolerant rice varieties in Nepal (Table 9). Drought tolerant varieties developed by IRRI such as IR 74371-46-1-1, IR 74371-54-1-1, and IR 74371-70-1-1 proved high-yielding varieties under drought conditions in the Gangetic Plains of South Asia including Nepal, India, and Bangladesh and these drought tolerant varieties have given different names in different countries, for e.g. Sukha Dhan (Fig. 4) in Nepal (Dar et al. 2020).

Fig. 4. Drought-tolerant rice variety (Sukha Dhan-6)

These varieties are recommended for Terai, inner Terai, mid-hills (River basin-Tar) of Nepal. These varieties can be cultivated as early (Bhadaiya), main-season (Agahani) and as direct seeded rice. Hardinath-3 is useful for spring season (Chaite Dhan) cultivation. These varieties are well adapted in rice-rice or rice-wheat or rice-lentil/gram cropping system.

Table 9. Drought tolerant rice varieties developed by NARC

Sl. No.	Name of variety	Crop duration (days)	Yield (t/ha)	Grain type
1	Sukhkha dhan-1	123-125	3.2-4.2	Fine
2	Sukhkha dhan-2	122-124	2.3-3.5	Medium
3	Sukhkha dhan-3	122-125	2.5-3.6	Fine
4	Sukhkha dhan-4	118-125	2.7-4.0	Fine
5	Sukhkha dhan-5	125-128	3.2-4.2	Medium/fine
6	Sukhkha dhan-6	120-125	3.0-4.0	Medium/fine
7	Haridnath-3	125	5.5	Fine
8	Khumal-10*	158	7.7	Fine

*Developed at National Plant Breeding and Genetics Research Centre. In the condition of aged seedlings (50-60 days old), this variety provides better yield as compared to other normal variety for mid-hills (Thakur et al. 2017).

NARC research programs and stations such as National Rice Research Program (NRRP), Hardinath, Directorate of Agricultural Research (DoAR) Parwanipur, DoAR Tarahara, DoAR Khajura and DoAR Doti are involved in production of source seeds of drought tolerant/stress tolerant rice varieties and these seeds are primarily distributed to their existing networks such as AKCs, CBSP groups, Cooperatives, Seed Companies and Participant and Contract farmers for seed production (Gauchan et al. 2014). These varieties are preferred by smallholders and women farmers. In the western Terai (Dang, Kailali, Banke, Bardiya) farmers have adopted Sukhkha Dhan-2, 3, 6 where farmers have been able to increase their income by 40% due to cultivation of these varieties instead of their regular varieties (LI-BIRD 2022).

Submergence-tolerant rice varieties

In Nepal, nearly 5% of the rice area (120 thousand ha) suffers from flash floods or shallow submergence (Gumma et al 2012; SARPOD 2012). In some areas, flood completely submerges (duban) rice fields for 5-10 days and yield loss may range 15-100% (Giri et al. 2016). Nepal Agricultural Research Council has released Swarna sub-1 (Fig. 5), Sambha Mansuli Sub-1, Chierang Sub-1 rice, Ganga Sagar-1 and Ganga Sagar-2 varieties for submerged condition (Table 10). The National Rice Research Program under NARC and the International Rice Research Institute (IRRI) have collaborated to develop flood-tolerant rice varieties in Nepal. These varieties can produce satisfactory yields under submerged conditions. Due to the presence of Sub-1 gene rice plant can survive even after submergence for up to 15 days having no yield penalty and these varieties can also perform well under normal conditions.

These varieties are suitable up to an altitude of 700 masl. It can be cultivated in Terai, inner Terai, and foothills. These varieties are well adapted to rice-rice or rice-wheat cropping systems.

Fig. 5. Submergence tolerant rice variety (Swarna sub-1)

Table 10. Submergence tolerant rice varieties developed by NARC

Sl. No.	Name of variety	Crop duration (days)	Yield (t/ha)	Grain type
1	Swarna sub-1	150-155 (normal) 160-165 (submerged)	4-4.45 (normal) 3-3.5 (submerged)	Fine
2	Sambha Mansuli sub-1	135-140 (normal) 150-155 (submerged)	4.5-5.0 (normal) 3-3.5 (submerged)	Fine
3	Chierang sub-1	122-125	4.4-4.9	Medium fine
4	Ganga Sagar-1	150	3.8 – 4.5	Medium
5	Ganga Sagar-2	145	3.5 – 4.5	Fine

Drought tolerant rice varieties

In Nepal, about 30% of the cultivated area suffers from drought due to lack of sufficient and timely rainfall, and about 15% comes under high flood (Giri et al. 2017). In some parts of the country, rice field comes under flood and drought situation simultaneously. Nepal Agricultural Research Council has developed Bahuguni Dhan-1 (Fig. 6), and Bahuguni Dhan-2 for occasional drought and flood conditions. National Rice Research Program under NARC and the International Rice Research Institute collaboration developed these varieties (Table 11). These varieties can produce satisfactory yields under both submerged and drought conditions.

These varieties are suitable up to an altitude of 700 masl. It can be cultivated in Terai, inner Terai and foothills. These varieties are well adapted to rice-rice or rice-wheat cropping systems.

Fig. 6. Drought tolerant rice variety (Bahuguni Dhan-1)

Table 11. Drought and submergence tolerant rice varieties developed by NARC

Sl. No.	Name of variety	Crop duration (days)	Yield (t/ha)	Grain type
1	Bahuguni Dhan-1	138	5.5	Fine
2	Bahuguni Dhan-2	145	5.8	Coarse

Cold tolerant rice varieties

Rice is cultivated from Terai to high hills up to 3,050 m in Nepal (Gadal et al. 2019). Rice cultivation area in high hills cover only 4% of the total rice cultivated area in Nepal (Thakur et al. 2017). The ambient temperature remains below 0°C and the irrigation water is also cold which caused cold injury and the major symptoms are slow growth, leaf discoloration, delayed heading, poor panicle exertion, spikelet degeneration, spikelet sterility and therefore poor yield (Upreti et al. 2013). In 2002, improved rice varieties Chandannath-1 and Chandannath-3 were released by the Nepal Agricultural Research Council which are Chinese origin of Japonica rice varieties and received from the

International Rice Research Institute (IRRI), the Philippines (Paudel 2011). Chandannath-1 is red rice and Chandannath-3 is white rice having productivity of 6.0 t/ha in Jumla condition (NARC 2007) while 2.5 to 3.5 t/ha in the farmers' field (Paudel 2011). These rice varieties are cold tolerant and have posed cold tolerant gene to thrive in cold temperature condition (Paudel 2011) and are suitable up to an altitude of 3,050 m. Majority of the farmers (70%) are growing Chandannath series of rice in Jumla conditions (Sapkota et al. 2010). Lekali Dhan-1 (Figure 7) and Lekali Dhan-2 released by NARC in 2014 for high hill condition (1,500-2,600 m) like Jumla in Karnali Province. These varieties are recommended for Jumla like areas.

These varieties (Table 12) have been disseminated by the formal seed system and the replacement of local varieties by improved ones the production trend seems to be stagnant which was due to lack of desirable variety with genetic traits of early maturity and less nutrient requirement (Sapkota et al. 2010).

Table 12. Cold tolerant rice varieties developed by NARC

Sl. No.	Name of variety	Crop duration (days)	Yield (t/ha)	Grain type
1	Lekali dhan-1	190-200 (high hill)	4.07	Coarse
2	Lekali dhan-3	190-200 (high hill)	3.90	Coarse
3	Chandannath-1	191 (high hill)	5.05	Coarse
4	Chandannath-3	192 (high hill)	5.39	Coarse

Fig. 7. Cold tolerant rice variety (Lekali Dhan-1)

Heat tolerant wheat varieties

Wheat is the third major food crop after rice and maize in Nepal in terms of area (0.71 million ha) and production (2.12 million ton) with the productivity of 2.99 t/ha (MoALD 2022). Late sowing of wheat due to several factors including after harvest of previous rice crop after rice harvesting results to expose high temperature during reproductive and grain filling stages causing shortening of grain filling duration, abortion of late forming florets and reduction in potential kernel number result in reduced grain yield (NWRP 2016). It is predicted that an increase of 1°C temperature can result in 6% loss global wheat production (Yu et al 2014). For wheat, optimum temperature during anthesis and grain filling stage ranges from 12 to 22°C and temperature above this decreases the grain yield (Tewolde et al 2006). Under drought stress, days to anthesis and days to maturity have reduced by 10% and 14% while under heat stress these were reduced by 16% and 20% respectively (Pokhrel et al 2021). National Wheat Research Program, Bhairahawa under NARC and International Maize and Wheat Improvement Center (CIMMYT) in collaboration have developed most of the heat tolerant wheat varieties in Nepal (Table 13). Bhrikuti released in 1994 can tolerate high temperatures in late sown conditions so, there is low grain yield loss (NWRP 2016). Gautam released in 2004 is an early maturity variety. This variety has low shattering loss stays green at the grain maturity stage, and resists high temperature and hot winds during the reproductive stage. Vijay (Fig. 8) and Aditya released in 2010 and 2009 respectively, have rapid grain filling trait under heat stress conditions (NWRP 2016). A recently released variety Borlaug 2020 is fortified with zinc and iron content and resistant to leaf rust, which is highly heat tolerant and popular in western Terai of Nepal. These varieties are recommended for Terai and foothills. These varieties can be well adapted to rice-wheat and rice-maize cropping systems.

Fig. 8. Heat and leaf blight tolerant wheat variety (Vijay)

In Bhairahawa condition, 47.6% yield reduction in wheat genotypes was observed under heat stress (late sown) condition as compared to normal sowing conditions (Poudel et al 2021). They also reported Bhrikuti, NL 1420, BL 4669 and NL 1350 as higher yielding capacity under normal and heat stress conditions.

According to Gauchan and Dongol (2015), area coverage by the wheat variety Gautam, Bhrikuti, and Vijay were 18.82, 13.61 and 5.80 percent respectively in Nepal during 2014. High quality genetically pure breeder and foundation seeds are produced mainly by NARC research stations to use for multiplication of next generation of commercial seeds (certified and improved) however, recently, private seed companies and some cooperatives are also authorized to produce source seeds (mainly foundation) for subsequent cycle of seed multiplication with close supervision and monitoring of seed certifying agencies (Timsina et al. 2018).

Table 13. Heat tolerant wheat varieties developed by NARC

Sl. No.	Name of variety	Crop duration (days)	Yield (t/ha)	Recommended domain
1	Gautam	119	4.3	Terai/Plains
2	Vijay	116	4.5	Terai/Plains
3	Bhrikuti	120	5.0	Terai/Plains
4	Banganga	117	4.5	Terai/Plains
5	Borlaug 2020	120	5.0	Terai/Plains

Heat, drought, and water-logging tolerant maize varieties

In Nepal, maize ranks second food crop after rice in terms of area (0.97 million ha) and production (2.99 million tons) with a productivity of 3.05 t/ha (MoALD 2022). In Terai and Inner Terai of Nepal, spring and early summer maize are cultivated while in mid-hills, foothills, and river basin areas are planted with spring maize and these areas are mostly affected by heat stress which reduces crop productivity (Koirala et al 2017). Spring maize planted in the maize-rice system is estimated to be about 15.5% of the total maize area affected by heat stress, and yield losses may reach up to 75% mainly because anthesis and silking stages coincide with high temperatures which cause leaf filling and tassel blast resulting poor pollination (Koirala et al 2013). The plant completes the grain-filling stage and reaches full maturity more quickly than usual when the maximum temperature is higher than 30-35°C, especially at night (Bhandari et al, 2013). This is due to a higher rate of dark respiration. A rise in temperature above 38°C reduces the pollen viability and silk receptivity resulting in poor seed set and reduced yield (Koirala et al 2017). Heat and drought stress seem to be a common problem worldwide, which can reduce maize productivity (Ali et al 2015).

National Maize Research Program (NMRP), Rampur in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT) has developed heat-tolerant maize varieties. Rampur Hybrid-8 (2017), Rampur Hybrid-10 (2017) (Fig. 9) and Rampur Hybrid-12 (2022) are the released single cross maize hybrids in Nepal (Table 14). These three hybrids are heat resilient and suitable to grow in the spring season up to 700 m altitude of Nepal. These hybrids can tolerate 40°C at peak flowering time. Rampur Hybrid-8 has a potential production of 6.8 to 11.4 t/ha, with an average yield of 9.18 t/ha and Rampur Hyrbid-10 has a potential yield of 7.7 to 12.0 t/ha, with an average yield of 8.79 t/ha. Similarly, Rampur Hybrid-12 has a potential grain production of 8.12 - 12.28 t/ha, with an average yield of 9.44 t/ha.

Fig. 9. Heat-tolerant maize varieties (Rampur hybrid- 8 and Rampur hybrid-10 and Rampur hybrid-12)

Drought Resilient Hybrids: CAH1817 and CAH 193 are drought-tolerant single cross hybrids having potential yields of 9.2 and 10.0 t/ha, respectively. These hybrids have a yield potential of more than 12.5 t/ha under optimal conditions. These are the other two pipeline line hybrids for release in Nepal.

Water-logging tolerance Hybrids: CAH1511 is another single cross hybrid tolerant against water-logging. This hybrid can produce more than 9.0 t/ha grain yield and performed well in summer season across the mid hills and winter season across Terai. This hybrid is in pipeline for release in 2023.

These all varieties are recommended for Terai and inner Terai and are well adapted in maize - rice cropping system.

Table 14. Heat, drought, and water logged tolerant maize varieties developed by NARC

Sl. No.	Name of variety	Crop duration (days)	Yield (t/ha)	Recommended domain
1	Rampur hybrid-8	110 (spring), 155 (winter)	7.55	Terai/inner Terai up to 700 meter
2	Rampur hybrid-10	120 (spring), 160 (winter)	8.05	,,
3	Rampur hybrid-12		9.44	,,

The important factors for the uptake of this technology are the involvement of public and private sectors in the research/demonstration blocks while selecting promising technologies, farmers' mobilization training, training to farmers, researchers, extension and development workers, large plot demonstration of technologies for promotion, farmers' day celebration at experimental and seed production sites, inter-district/inter-site observation tour, implementation of farmers' field school program, preparation and distribution of extension materials in native language, publication through press and electronic media and stakeholders' workshop. Likewise, challenges for up-scaling of this technology are costlier quality seed, unavailability of required inputs on time, increasing cost of inputs, outbreak of new maize diseases, seed demand increasing but supply limited, climate change (increased incidence of drought, heat, cold stress, and flood) (Koirala 2017).

Drought-tolerant potato genotypes

Potato is one of the major important tuber crops of Nepal. It is grown from Terai to the mid-hill and high hills area. The central region of Terai covers the largest area for potato production. Lack of irrigation is one of the major limiting factors for the lower productivity of potatoes. Under rainfed conditions**,** potato clones; 393280.64, 386612.5, 391004.18, 397077.16, 393077.15, and 389746.2 were found resistant to drought under central Terai conditions (RARSP 2012). Similarly, in mid hills of Khumaltar condition, CIP 304003.161, CIP 392243.17, CIP 391058.35, CIP 392242.25, and Khumal Seto 1 have recorded satisfactory yields under rainfed conditions.

Soybean genotypes tolerant to short period submergence

Soybean (*Glycine max* L. Merril) is the most important legume crop of Nepal having high nutritional, environmental and industrial values which is widely cultivated from Terai to Hilly regions (Pokhrel et al 2021). It is mainly cultivated in hilly areas but due to increasing demands in livestock and poultry feed, it is becoming popular in Terai and inner Terai area also (Pokhrel et al. 2013). In soybean, soil water logging or flooding stress is the major abiotic stress influencing production (Ye et al. 2018) causing 25% yield reduction (VanToai et al. 2010).

In Terai region, high soil moisture stress owing to heavy rainfall during the early growth stage is the most limiting factor affecting the growth and productivity of soybean in Nepal (Pokhrel et al 2021). Genotypes TGX 1990-94F (1883 kg/ha), SBO–115 (1699 kg/ha) and TGX 1987–62F (1603 kg/ha) were identified as the highest yielder in high soil moisture stress conditions when more than 5 cm water level remained for continuous 7 days at 30 days after sowing (DAS). These genotypes are under the releasing process and are recommended for the Terai region in high soil moisture conditions.

5.1.2 Crop and livestock insurance schemes

Crop and livestock insurance scheme has become one of the important climate risk mitigation and adaptation strategies in tackling adverse climate impacts in Nepal. Sharing the burden of financial risk from yield losses can be achieved through agricultural insurance (Mahul et al 2012). The Nepalese government subsidizes insurance by paying 80% of the premiums in order to assist farmers in risk management, avoid financial losses, and promote farmer involvement in insurance programs (NIB 2022). Nepal Insurance Board (NIB) has been providing agriculture insurance through 29 policies for crop, fruit, and livestock sectors including weather index policy.

5.1.3 Protected cultivation technology for vegetable production

Plastic house tomato cultivation technology is one of the successful technologies being adopted widely by farmers in Nepal. Shade net is another way of protecting crops from many harsh environmental factors including excessive sunlight (llic et al. 2011), heat and drought (Meena et al. 2014), wind and hail (Teitel et al. 2008), and moving insects (Shahak 2008), which ultimately improve the yield and quality of crops. Plastic house technology (Fig. 10) is one of the viable alternatives for quality tomato production in the high hills (Chapagain et al 2010). Because of low temperatures, high rainfall during the flowering stage, and blight disease limit tomato cultivation in open field conditions in high hills (Pandey and Chaudhary 2004). The plastic house tomato production technology helps reduce the use of pesticides and is gaining popularity among farmers day by day as a new frontier in the eastern high hills of Nepal (Chapagain et al 2010). Horticulture research station, Malepatan, Pokhara has recommended different cropping patterns of vegetable production under protected cultivation for mid-hill conditions (Table 15).

Fig. 10. Plastic house technology for vegetable production

Table 15. Vegetable cropping patterns under plastic house in mid-hill (Pokhara condition)

Sl. No.	Crops	Varieties	Planting time	Harvesting time	Production (t/ha)
1.	Tomato	Srijana	July	October-November (90-100 days after transplanting, 10 harvest)	105
2.	Capsicum	California wonder	July-August	October-November (85-110 days after transplanting, 3 harvest)	40
3.	Cucumber	Parbati, Beli, Brisma	July and January	October-November and March-April	90-130
4.	Rayo	Manakamana	July	35 to 45 DAT, 8 pickings	40-55
5.	Coriander	Kalami	July	60-65 days, 3 pickings	15-25
6.	Carrot	New Kuroda	June-July	August	25-35
7.	Radish	Mino-early and 40 days	June-July	August	18
8.	Beans	Four Seaon, Italy-38	June and November	September-October and January-February	25-30

5.1.4 Climate smart housing for livestock

In the context of changing climate, a suitable shelter design is needed for the livestock breeds. Such design of climate smart housing characterized with heat stress reduction, methane mitigation, and waste and space management for different breeds. Suraj (2011) has recommended a scientific design to improve the comfortable level for optimizing production in livestock (Table 16).

Table 16. Climate Smart housing consideration for livestock in Nepal

Components	**Cattle/Buffalo**	**Sheep/goat**	**Pig**	**Poultry**
Floor	Cement, concrete and slip resistant floor Rubber flooring (in temperate condition) Dry, softer elastic Stall with softer floor	Height of floor 1 -1.5 m above the ground Concrete or wooden slat and 1.3 - 2 cm gap between slats Soft floor for sheep	Hard concrete and sloppy (2-3% toward manure allay (Thirupathy and Usha 2011) Easy to clean	Concrete floor and good litter materials Mud floor (reduce cost)
Roof and Roofing materials	Reflective to solar radiation Aluminum sheet Tropical climate Cheap and Locally available material like straw, tiled etc.	Should be water proof Thatched roof with greater slope in high rainfall area Can be constructed from locally available materials and climate eg. Paddy straw, earthen tile, tin sheet etc	Simple with open sided structure Asbestos cement or Locally available materials like wild grass thatched Roof insulated by layer of thatching like coconut leaves	Thatched and tiled roof To avoid direct radiation roof overhang should be 3-5 ft.
Different Ameliorative method	-Wet gunny bag for wetting body -Bathing animal frequently -Tree Plantation -Hanging wet gunny bag against wind direction		Overhead sprinkles and shower during summer Poll or Wallowing tank of cement	
Water and feeder		Water bowl Water nipple	Bowl drinker or ball bite nipple Positioned 10-15cm above backline Width of trough not less than 50cm	
Methane mitigation	Construct bio gas digester Aerobic composting		Proper waste management As alternative biogas establish biogas unit Use Biogas digester	

5.1.5 Stress tolerant animal breed

Twenty-six indigenous breeds have been identified in different agroecological zones of Nepal based on the climate, animal husbandry practices, socio-economic value, and ethnological preference and in some cases by marketability (Gorkhali and Neupane 2008). Indigenous breeds are well adapted to different climatic conditions and acquire positive attributes like heat or cold resistance, hardy to withstand adverse climatic conditions, manageable in low input systems, disease/parasite resistant, etc.

The indigenous breeds of livestock with home tract, characterization, and positive attributes to adapt to climate variability are presented in Table 17.

Table 17. Indigenous animal breeds with positive attributes

S. N.	**Breeds**	**Scientific name**	**Region/area**	**Population status**	**Characterization**	**Positive Attributes**
1. Cattle						
1.1	Terai Cattle	*Bosindicus*	Across the Terai	Normal	Phenotypic+DNA	Suitable for Terai plain land, hardy, good draught breed
1.2	Pahadi Cattle	*Bosindicus*	Across the hills	Normal	Phenotypic	Suitable for the low and mid-hills across the country, hardy
1.3	Khaila	*Bosindicus*	Far western region (Dadeludhura, Doti and Baitadi districts)	Population decline	Phenotypic	Suitable for mid-hills, good temperament, draught breed
1.4	Lulu	*Bostaurus*	Mustang, Dolpa, Manang	Population declining	Phenotypic+Chromosomal+DNA	Hardy, suitable for cool and dry climate, good for low input system
1.5	Achhami	*Bosindicus*	Far western region (Achham, Bajhang, Bajura and Doti districts)	Risk	Phenotypic+Chromosomal+DNA	Suitable for hills, smallest breed of the world, produce in low input
1.6	Siri	*Bosindicus*	Ilam, Panchthar and Taplejung district	Nearly Extinct	Phenotypic+DNA	High yielding, suitable size for hills
1.7	Yak / Nak	*Poephagusgrunniens*	Mountain regions	Population decline	Phenotypic+DNA	Hardy, can survive at high altitudes, pack use in high mountains
2. Buffalo						
2.1	Lime	*Bubalusbubalis* (Type: Riverine)	Hilly areas; specially Gandaki Province.	Population declining and at risk	Phenotypic+Chromosomal	Good milk yielder, adapted to harsh climatic environments, good meat, adapted to low and mid hills
2.2	Parkote	*Bubalusbubalis* (Type: Riverine)	Hilly areas; specially Gandaki province.	Population declining, but not yet at risk	Phenotypic+Chromosomal	Suitable for hills, good milk yielder, adaptable to harsh environments
2.3	Gaddi	*Bubalusbubalis* (Type: Riverine)	Far-western hills	Population declining and at risk	Phenotypic+Chromosomal	Suitable for hills, high milk yielder, adaptable to harsh environments
2.4	Terai Buffalo	*Bubalusbubalis* (Type: Riverine)	Eastern Terai region of; specially Moran and Sunsari districts	Population declining but not yet at risk	Phenotypic+DNA	Suitable for tropical climate, good meat quality

S. N.	Breeds	Scientific name	Region/area	Population status	Characterization	Positive Attributes
3. Goat						
3.1	Terai Goat	*Capra hircus*	Across the terai region	Population declining, pure line hardly exists	Phenotypic+Chromosomal+DNA	Suitable for terai conditions, hardy, good meat breed
3.2	Khari	*Capra hircus*	Across the hill region (mainly in low to mid hills)	Normal	Phenotypic+Chromosomal+DNA	Hardy, prolific, suitable for hill conditions, good for low input system, good meat type
3.3	Sinhal	*Capra hircus*	High hills and mountains	Population declining	Phenotypic+Chromosomal+DNA	Hardy, suitable for high hills, largest indigenous goat breed, produce in low input, good for pack
3.4	Chyangra	*Capra hircus*	High hills and mountains	Population declining	Phenotypic+Chromosomal+DNA	Hardy, suitable for high hills and mountains, good pack breed, can produce *pashmina*
4. Sheep						
4.1	Lampuchhre	*Ovisaries*	Terai districts (Banke,Bardia, Dang, Kapilbastu, Nawalparasi, Sunsari)	Risk	Phenotypic+Chromosomal+DNA	Suitable for terai conditions, hardy, good fighting quality, meat type
4.2	Kage	*Ovisaries*	Across the lower hills, inner valleys	Population declining	Phenotypic+Chromosomal+DNA	Suitable for lower hills, hardy, coarse wool type suitable for making *radi/pakhi*
4.3	Baruwal	*Ovisaries*	Across the mid hills	Normal	Phenotypic+Chromosomal+DNA	Suitable for hills, hardy, wool suitable for *radi/pakhi*, principal breed, good grazing instinct
4.4	Bhyanglung	*Ovisaries*	High hills and mountains in Transhumance system	Population declining	Phenotypic+Chromosomal+DNA	Hardy, suitable for high hills and mountains in Transhumance system, carpet type wool
5. Pig						
5.1	Chwanche	*Susdomesticus*	Across the hills	Population declining but not yet at risk	Phenotypic+Chromosomal+DNA	Suitable for hills, disease resistant, hardy, suitable for backyard rearing
5.2	Hurra	*Susdomesticus*	Across the Terai	Population declining but not yet at risk	Phenotypic+Chromosomal+DNA	Suitable for Terai, strong body, hardy, suitable for backyard rearing
5.3	Bampudke	*Porculasalvania*	Few terai districts near Chure hills (Nawalparasi, Chitwan, Dang, Kailali etc.)	Risk (about to be extinct)	Phenotypic+Chromosomal+DNA	Smallest hog breed, both wild and domestic, quality of meat

S. N.	Breeds	Scientific name	Region/area	Population status	Characterization	Positive Attributes
6. Chicken						
6.1	Sakini	*Gallus gallusdomesticus*	Throughout the country	Normal	Phenotypic+Chromosomal+DNA	Hardy, suitable for scavenging, dual purpose, tasty meat
6.2	GhantiKhuile	*Gallus gallusdomesticus*	Throughout the country in limited pockets	Risk	Phenotypic	Hardy, suitable for scavenging, dual purpose, tasty meat
6.3	PwakhUlte	*Gallus gallusdomesticus*	Throughout the country in limited pockets	Risk	Phenotypic	Hardy, suitable for scavenging, dual purpose, tasty meat
7. Horse						
7.1 Jumli	Jumli Horse	*Eqqusferuscaballus*	High hill districts like Jumla, Dolpa. Seasonal migration to terai districts like Dang, Bake, Kailali, Kanchanpur etc.	Population declining but not yet at risk	Phenotypic	Suitable for hills and mountains, hardy, strong and sure-footed, disease resistant, adaptable to harsh environments

Source: Indigenous Animal Genetic Resources of Nepal: a reference book (2022)

Genetic improvement of the indigenous breeds is an effort to increase production and to the adaptation of livestock populations to challenges such as climate change, pressures on feed, emerging diseases, and water resources.

5.2 Water smart CSA technologies

5.2.1 Laser Land Leveler (LLL)

The laser land leveler is a prerequisite for the successful implementation of water conservation technologies. It is easy to operate most of the agricultural operations on the leveled land which is achieved by laser land leveler. It is considered a climate-smart technology as it contributes to reducing greenhouse gas emissions through its potential to decrease water pumping time by 10-12 h/ha/season for wheat and by 47-69 h/ha/season for rice cultivation, and decrease cultivation time and energy savings equivalent to US$ 143.5/ha (Aryal et al 2015; Gill 2014). This technology helps in proper and uniform germination of seeds, saves irrigation water, increases fertilizer use efficiency, and finally higher crop yield. It can level 2-3 ha of land/day. There is a very high demand for this machine/technology by the farmers of the eastern region of Nepal.

Specifically, in the areas where farmers use structures like bunds, dikes, and ditches on the flat plots and subplots even with relatively similar elevation, LLL (Figure 11) could be a climate-smart precision technology to save irrigation water, labor costs, reduce fuel costs and contribute to lower greenhouse gas emission. However, the adoption rate of LLL system has not gained momentum in Nepal. One of the important reasons is that farmers with relatively low resources are not able to purchase the LLL system (Poudel et al 2022).

Fig. 11. Land leveling by laser land leveler

NARC research centres in collaboration with CIMMYT have demonstrated this technology in many outreach sites. Awareness and willingness of farmers on LLL are increasing, however, the purchase of LLL system requires significant capital which could be beyond the access of resource-poor farmers (Poudel et al 2022). Promotion of this technology is possible through a custom hiring scheme. Many programs including PMAMP have promoted custom hiring in Nepal for agriculture mechanization. Adoption of LLL technology can easily be increased through custom hiring services, particularly in plain areas.

5.2.2 Water efficient production techniques

Direct seeded rice (DSR)

Transplanting and direct sowing of rice are the most common methods of crop establishment.

Rice is grown in three ecosystems in Nepal - rainfed upland, rainfed lowland, and irrigated lowland. DSR technology is mostly used for rainfed lowland and upland production systems.

In the transplanting system, rice seedlings are transplanted in the puddled field which requires huge amounts of water and higher numbers of labor for uprooting seedlings, puddling fields, and transplanting seedlings in main fields (Pandey and Velasco 1999).

Direct seeding of rice (DSR) refers to the process of establishing crop from seeds sown in the field rather than by transplanting (Farooq et al. 2011) which is more economical due to labor and water saving (up to 40 and 60%, respectively), early maturing of rice crop (7-10 days), energy saving (up to 60% of diesel), reduction in methane emission, less drudgery to farm women, reduced cost of cultivation, and enhanced system productivity (Pathak et al. 2011). DSR systems are classified into (i) dry-direct seeded rice (DDSR) (Fig. 12), (ii) wet-direct seeded rice (Fig. 13), and (iii) water-seeded rice. In DDSR, rice is established using several different methods, including (i) broadcasting of dry seeds on unpuddled soil after zero tillage or conventional tillage, (ii) dibbled method in a well-prepared field, and (iii) drilling of seeds in rows after conventional tillage, reduced tillage using a power tiller-operated seeder, zero tillage or raised beds (Kumar and Ladha 2011).

In wet direct seeded rice, seeding involves sowing of pre-germinated seed, with a radical varying in size from 1 to 3 cm, on or into puddled soil (Balasubramaniam and Hill 2002). For this, usually drum seeder is used. In water-seeded rice, pre-germinated seeds are broadcasted in standing water on puddled or unpuddled soil. Beside irrigated areas, water seeding is practiced in areas where early flooding occurs and water cannot be drained (Kumar and Ladha 2011). This DSR technology is women farmer friendly.

Fig. 12. Dry-DSR using tractor mounted drill.

Fig. 13. Wet-DSR using drum seeded

Productivity of upland rice depends on several climatic parameters (temperature, rainfall, humidity, etc.), hydrological properties of soil (pH, organic carbon, cation exchange capacity, etc.), rice varieties, and major production inputs, such as fertilizer management practices (AGD 2017).

National Agronomy Research Centre, Khumltar has recommended upland rice technology because:

☐ It preserves the physical properties of soil;
☐ Harvesting is 7-15 days earlier as compared to transplanted rice;
☐ It facilitates in-time rice sowing and provides sufficient time for the next crop;
☐ It saves 50% on production costs compared to transplanted rice;
☐ 35-45 less labor is required for one hectare of rice cultivation;
☐ It saves 30-40% of irrigation water;
☐ Energy consumption is reduced by 27 %;
☐ It significantly reduces ammonia emissions;
☐ Rice yield remains unaffected.

Both NARC and agriculture universities/colleges are involved in conducting various experiments on DSR.

For the Terai areas, IR05N341, IR12A190, IR11A325, and IR11A306 genotypes are suitable for DSR in the rainy season while Hardinath-1, IR92521-173-1-1-1, IR93835-73-23-1, and IR93821-41-1-2-1 for spring season rice (NRRP 2015). In mid-hill condition, NR 10490, NR 10676, and 08 FAN 10 are the promising genotypes for DSR (AGD 2017).

System of rice intensification (SRI)

The system of rice intensification is a method for increasing the productivity of rice by changing the management of plants, soil, water, and nutrients (ICIMOD 2008). The three basic principles of SRI are: to encourage early and healthy plant establishment, reduce competition among plants, build up fertile soils with organic matter and beneficial soil biota, and manage water to avoid both flooding and water stress (SRI-Rice 2016). Paddy rice cultivation represents 9-11% of the total agricultural GHG emissions (IPCC 2014) but SRI contributes to mitigating emissions of greenhouse gases (GHG) especially methane (CH4) gas which is reduced between 22% and 64% due to alternate wetting and drying (Jain et al 2014). SRI plants thrive well with 30-50% less irrigation water compared to flooded rice cultivation and they have thicker tillers and deeper roots as they are more widely spaced (Styger and Uphoff 2016). The major limitation of SRI is the higher labor cost involved in weeding in the initial stage (Bhatta and Tripathi 2005).

System of rice intensification was first introduced in 1998 in Nepal with some initial experiments at Khumaltar, Lalitpur (Evans et al 2002). In 2002-2003, the Farmers Field Schools under Sunsari-Morang Irrigation Project conducted replicated SRI trials which produced an average grain yield of 8 t/ha which was more than that produced by improved or conventional farmers practice (Uprety 2006). In 2008, SRI was tested in Terai region of Nepal and there was a 28% yield advantage with 20 x 20 cm and 33% yield advantage with 30 x 30 cm planting spacing over farmers' practice with manual weeding (NARC 2008). Similarly, in Chitwan condition, SRI recorded 49% higher grain yield as compared to farmers' conventional practice (Dhital 2011). Jhikhu Khola a middle mountain area of Nepal, SRI recorded up to 90% yield increase over traditional methods under controlled irrigation management (Dhakal 2005).

In the western Terai region, SRI with 8 and 15 days of seedling with crop geometry of 25 x 25 cm recorded the highest yield as well as the highest gross return, net return, and B: C ratio (Dahal and Khadka, 2012). In another study at Bajhang, SRI recorded 70% more yield than the conventional transplanting method (Khadka et al 2014). Higher methane gas emission was observed in the non-SRI system of rice cultivation (125 μg $CH_4/m^2/h$) as compared to the SRI system (30 μg $CH_4/m^2/h$) (Raut et al 2020). For areas with erratic rainfall patterns and prolonged drought conditions, SRI could be an appropriate technology for rice cultivation. This technology is appropriate for areas having rich soil organic matter, but limited water availability such as the western part of Nepal and in hill farming systems where the field is fed by the streams with a controlled irrigation system (Dahal 2014).

5.2.3 Water efficient irrigation system

Alternate wetting and drying irrigation system for rice

Rice grown under conventional transplanting systems in tropics and sub-tropical areas requires water between 700 and 1,500 m of water for the rice cropping season (Bhuiyan 1992). Similarly, under this system, there is a high amount of surface runoff, seepage, and percolation. Therefore, the efficiency of water use in irrigated rice production systems must be significantly increased and one such strategy is to use of alternate wetting and drying (AWD) method of irrigation in rice (Chapagain and Riseman 2011). This technology was developed by IRRI, Phillippines. It is reported that the AWD system in rice (Fig. 14) reduces water use by up to 30% and methane emission by an average of 48% as compared to continuous flooding (Richards and Sander 2014). In the Terai condition of Nepal, this technology was reported to save 54.5% of irrigation water as compared to the conventional irrigation system (Yadav et al. 2012).

Howell et al (2015) reported a similar yield of spring rice under AWD and continuous flooding plots in Nepal, however, AWD plots received on average 57% less irrigation water than continuous flooding plots. AWD can be practiced in the Terai and mid-hills regions of Nepal. It can be practiced in all types of soil except sandy and heavy clay soil where water drains quickly in sandy soil and soil water never drops below the deepest roots of rice in heavy clay soil (Belder et al 2004). This technology is mostly suitable for the dry season (more than 90%) while less in the wet season (about 34%) (Sander et al. 2017) and is gender friendly.

Fig. 14. Alternate wetting and drying irrigation for rice cultivation

Drip Irrigation

Drip irrigation is a water-efficient and climate-smart irrigation system. It is also suitable for smallholder farmers and is gender friendly. It essentially entails dripping water to individual plant root zones at low rates from emitters embedded in small-diameter plastic pipes. This technology not only saves the time and cost of irrigation and applying fertilizers but also increases the income of farmers because it ensures early harvesting among other benefits. Furthermore, drip irrigation (Fig. 15) also increases soil moisture and reduces water and soil loss.

Drip irrigation has several advantages over other methods of irrigation including:

- High water use efficiency;
- Increased yield for reduced plant stress;
- Labor-saving;
- Utilizing fertigation and dissolved agricultural inputs along with irrigation water;
- Easy installation;
- Reduced pest problems and weed growth;
- Versatility of use in different land terrains.

Fig. 15. Drip irrigation technique

Sprinkler Irrigation

Sprinkler irrigation is the method of watering the plants by which water is sprayed on the ground in the form of rainfall. Small sprinklers are useful when irrigating sloppy land, and narrow terraces where the water source is of low discharge. To create the precipitation, water under pressure is ejected through the nozzle of the device called as a sprinkler (Fig. 16). Sprinkler irrigation is suitable for any topography, soils and crops where other surface irrigation is inefficient or expensive or soil erosion is hazardous. Various forms of sprinkler designs are available. In Nepal, sprinkler irrigation was first introduced by ADB in mid-80's. At that time mostly rotary impact sprinklers with metal heads were in use. After some years, sprinklers made with plastic material in various designs became available through the efforts of private sector companies. Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils. The average application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided.

The pump supply system, sprinklers, and operating conditions must be designed to enable a uniform application of water. Sprinkler irrigation is suited for the most row, field, and tree crops and water can be sprayed over or under the crop canopy. Sprinkler irrigation is adaptable to any farmable slope, whether uniform or undulating. The lateral pipes supplying water to the sprinklers should always be laid out along the land contour whenever possible. This will minimize the pressure changes at the sprinklers and provide uniform irrigation.

Performance evaluation of different models of sprinklers has been done at different stations under NARC. A study was conducted on the irrigation system (surface and sprinkler) at Chhar-Ghare of Chapagaun, Lalitpur district of Nepal. The study revealed that the profit per cubic meter of water was NRs. 14.52 and NRs. 23.68 for surface and sprinkler irrigations, respectively. Higher grain yield of maize was obtained from the sprinkler irrigation system (7986 kg/ha) as compared to the surface irrigation method (6970 kg/ha). Similarly, the higher total return of NRs. 5772750 was recorded from the sprinkler irrigation system than NRs. 5503200 from the surface irrigation system. Thus, sprinkler irrigation was almost one and a half fold economical and profitable than surface irrigation (Shrestha and Dahal 2015). This technology is also favorable for smallholder farmers including women. For the promotion of this technology, awareness should be created through training and large demonstration trials, visits, farmers' field schools, public and private partnership programs, and support from the government.

Fig. 16. Sprinkler irrigation technique

5.2.4 Rainwater harvesting

In the context of climate change and irregular rainfall patterns, rainwater harvesting (RWH) technology (Fig. 17) plays a vital role in enhancing the socioeconomic status of rural farmers of Nepal (Adhikari et al 2018). RWH technology is relatively recent and the government is promoting it with other irrigation systems like drip irrigation and treadle pumps as a part of the irrigation policy (MOI 2014). This technology is also appropriate for rainfed areas where there is not a sufficient supply of ground or surface water.

A study conducted by six village development committees (Manhari, Basamadi, Bhimphedi, Palung, Hadikhola, and Aamvanjyang) of Makwanpur district reveals that about 80% of the cropping pattern of RWH adopters changed after the adoption of the technology. The farmers adopting RWH technology have 48% more farm income than non-adopters. Farmers with members of any organization like agriculture cooperatives, saving and credit groups, and livestock have the probability of adopting of rainwater harvest technology increased by 19% (Adhikari et al 2018). Earlier, a survey conducted at 26 VDC of Makwanpur district reported that 79% of the households with access to RWH technology sold their agricultural products resulting in average earnings of nearly US$ 700 per year from the sale of vegetables and nearly half of this income was due to increased productivity (Singh et al 2013).

This technology is women-friendly which reduces the workload for collecting water. It also helps produce year-round high-value crops. For the promotion of this technology, awareness should be created through training and large demonstration trials, visits, public-private partnership programs, and support from the government on plastic sheets, etc.

Fig. 17. Rainwater harvesting plastic pond

5.2.5 Pond water depth and fish productivity

Nepal has plenty of seasonal and shallow ponds facing the problem of insufficient water for growing fish in the annual production cycle. Low productivity of fish (< 3 mt/ha) with carp polyculture from shallow and seasonal ponds has been reported (Fig. 18). Depth as a factor in pond ecosystem management has been given little attention. Climate is an environmental factor that is strongly associated with aquaculture productivity. Shallow and rainfed ponds are more prone to climate change-related phenomena. Emerging trends in climate change would also play a vital role in further examining the water crisis.

Participatory research conducted by maintaining different water depths (<80 cm, 90-100 cm and 120-140 cm) at Chitwan for 205 days suggests that there is no correlation between water temperature and water depth of ponds, however, there is an inversely proportional relation between water loss in the pond and fish yield, irrespective of categories of experimental ponds. Harvest size (444.6 g) of fish and survival rate of fish (91.7%) were in deeper ponds. The findings of the research indicate that a pond depth of 120 cm or above had a significant impact on improving the carp fish yield. Decreasing water level had a negative impact on the growth and fish yield (FRD 2017).

Fig. 18. Pond water depth for fish production

5.2.6 Sloping Agricultural Land Technology (SALT)

In the hilly areas of Nepal, cultivation of crops on sloppy land is common. Due to a lack of soil conservation practices, there is severe soil erosion and it is estimated that soil loss due to surface erosion ranges from 2-105 Mt/ha/year from agricultural land in hills and mountains (Chhetri 2011). Resource conservation technology like Sloping Agricultural Land Technology (SALT) can reduce soil loss. In SALT technology, hedges rows crops (Fig. 19) are planted along the contours of sloping land at intervals of four to six meters in double rows, and different annual cereals and perennials cash crops are cultivated in the alleys (Lamichhane 2013).

In the maize-based cropping of mid-hill, the SALT system with nitrogen-fixing plants can significantly control runoff and soil loss. This system with *Alnus nepalensis* (Uttis) and/or *Indigofera dosua* also was reported to increase maize yield by retaining soil water nutrients (NPK). Therefore, integrating soil conservation approaches into SALT systems enhances stable economic output for hills and mountain farmers (Lamichhane 2013). From a 5-year long study conducted in hilly areas of Nepal, Maskey (2003) reported the lowest runoff (146 m^3/ha) as well as the highest yield of maize and buckwheat when farmer's practice was integrated with Sissoo (*D. sissoo*) as hedgerows.

Fig. 19. Farming in the slopes with hedge rows

5.3 Energy smart CSA technologies

5.3.1 Zero tillage

Zero till (ZT) technology refers to the method of placing seeds in soil with the help of a seed drill without prior land preparation and about 30% of the soil surface should be covered by crop residues at the time of planting (CSISA 2018). A tractor-drawn ZT seed cum fertilizer drill is used for seeding of rice, wheat, maize, lentil, chickpea, mustard, and green gram. It can also be successfully used under small-scale farming conditions using a two-wheel tractor (CSISA 2018). Agriculture Implement Research Centre (AIRC), Ranighat championed this technology in Nepal. Many NARC research centres and commodity programs have evaluated this technology at the research station and farmer's field.

Zero tillage technology is an energy-smart CSA technology which is popular in Terai and the foothills of Nepal. It is suitable for a rice-wheat cropping system. It saves land preparation time, therefore, on-time seeding of crop is possible. In this system, seeds and fertilizers are placed at the same time and it improves the fertilizer use efficiency. It is also a water-smart CSA technology which helps save more 30% irrigation water as compared to conventional wheat sowing. Some studies have shown up to 20% yield increment with this technology. Due to the residue of the previous crop and less soil disturbances, it maintains the physical properties of soil and minimizes erosion.

Zero tillage wheat

There should be sufficient moisture at the time of sowing wheat under zero tillage, if not one pre-sowing irrigation is necessary. In ZT wheat (Figure 19), less fertilizer and seed per unit area is used and there is less consumption of fuel as compared to conventional tillage-based wheat sowing. It also minimizes the water requirement for irrigation and there is a higher benefit-cost ratio as compared to conventional plowing. NRRP (2015) reported less seed, irrigation, tillage, and labor requirement in ZT wheat with higher grain yield (3,452 kg/ha) and net benefit as compared to conventional tillage-based cultivation.

In Nepal, 21% of the land is under agricultural crop production (MoALD 2022) and among them, less than 2% area is under zero-till (ZT) wheat (Pandey et al 2020). The major constraint to the cultivation of wheat in Indo-Gangetic flood plains (IGPs) including Nepal is the late planting of wheat due to the late harvesting of long-duration rice varieties. Similarly, wheat grown under traditional practices appears to be less productive and less profitable due to increasing input costs and intensive land preparation (Timalsina et al 2021). So, ZT is becoming popular for the timely sowing of wheat.

There should be sufficient moisture at the time of sowing wheat under zero tillage if not pre-sowing irrigation is necessary. In ZT wheat (Fig. 20), less fertilizer and seed per unit area is used and there is less consumption of fuel as compared to conventional tillage-based wheat sowing. It also minimizes the water requirement for irrigation and there is higher benefit-cost ratio as compared to conventional plowing. NRRP (2015) reported less seed, irrigation, tillage and labor requirement in ZT wheat with higher grain yield (3,452 kg/ha) and net benefit as compared to conventional tillage-based cultivation.

Fig. 20. Wheat early and late stage under zero-till machine sowing

The recent trend of conventional wheat sowing in Madhesh Province is the use of tractor driven rotavator. A recent study showed about 10% increase in yield of wheat with ZT as compared to rotavator system (AIRC 2022). ZT wheat is also economically beneficial to the farmers as it provides 38% more net economic benefit (NRs. 54,226/ha) as compared to conventional tillage (NRs. 39,298/ha) (Pandey et al 2020).

Zero tillage lentil

Lentil is an important pulse crop of Nepal grown in the winter season after rice. It occupies about 60% of the total grain legume production in Nepal (MoALD 2022). Farmers usually cultivate lentil as rainfed crop both under ZT and CT practices (Pokhrel and Soni 2018). NRRP (2015) reported higher grain yield (2,475 kg/ha) of lentil in zero tillage condition of Terai with savings of 16.66% in irrigation, 16.66% in tillage, and 30.09% in labor as compared to conventional tillage method. Similarly, ZT produced a higher B:C ratio (2.05) as compared to CT method (1.83). In the western part of Nepal, zero tillage lentil produced 5.92% higher yield than conventional tillage (Prasai et al 2018), while it was 31% higher in the midhill condition of Khumaltar (AGD 2016).

Zero tillage rice

In Nepal, there are two methods of rice cultivation i.e. puddled transplanting and direct seeding. In direct seeding, rice is cultivated as dry direct seeding or under zero tillage conditions. In zero tillage rice, there is no need to prepare a nursery so, there is a reduction of cost in labor for seeding, weeding, and irrigation. Bastola et al (2021) reported similar grain yield under zero tillage DSR and puddled transplanting rice in Chitwan condition. Likewise, AIRC (2022) also reported similar results in Bara and Parsa conditions. In the eastern part of Nepal, it was reported that the average total cost of production was lesser (NRs 49,515) in zero tillage as compared to conventional puddled transplanted rice (NRs. 68,172) (RARST 2015) with similar income.

Zero tillage maize

Maize is the second most important crop in Nepal after rice. It is usually cultivated under an intensive tillage system with 2-3 ploughings and at least two intercultural operations for weeding and earthing-up. Intensive tillage causes soil erosion and has a negative impact on environmental quality by accelerating soil carbon loss and greenhouse gas emissions (Reicosky and Allmaras 2003). Similarly, there is a higher production cost than harvesting (Edwards and Smith 2005). In the Chitwan condition, NMRP (2017) reported higher grain yield of maize varieties (RML-95/RML-96, Rampur hybrid-4, HGB ZM-401, and Rampur composite) under zero tillage as compared to conventional tillage during winter season. In the mid-hill condition of Lamjung, Shrestha et al (2019) found a higher grain yield of maize under zero tillage (5,584 kg/ha) than conventional tillage system (3,981 kg/ha). A higher B: C ratio (2.06) was observed in zero tillage as compared to conventional tillage maize (1.72) in the eastern part of Nepal (RARST 2015).

5.4 Nutrient smart CSA technologies

Increasing food demand due to the increasing human population with a decline in available agricultural land causes high pressure on the current agriculture production system and farmers have to overuse chemical fertilizers and other agricultural inputs (Jat et al. 2015). In Nepal, soil nutrient mining, reduction of soil organic matter, soil erosion in hills and mountains, and inappropriate use of chemical fertilizers in the Terai region result in declined soil fertility (Tripathi et al. 2022). Nutrient management in soil is one of the major factors in crop production systems. As there is pressure to grow more crops from the limited agricultural land, soil and crop management practices have a great role in higher production. High-yielding variety for one locality may not be successful in another agro-climatic region with different soil fertility conditions. Balanced use of nutrients is a key factor for higher crop yield.

5.4.1 Integrated nutrient management

Integrated nutrient management (INM) is a balanced and judicious use of chemical fertilizer with organic manure to improve soil physical, chemical, and biological properties (Rani et al 2019). The loss of nutrients through leaching, runoff, volatilization, emissions, and immobilizations is minimized with higher nutrient use efficiency under INM practices (Zang et al 2012). The major components of INM are the integration of green manure, legumes, recycling of crop residues, use of organic manure like FYM, compost, vermicompost, biogas slurry, poultry manure, press mud cakes, utilization of biological agents, balanced use of fertilizer nutrients as per yield target (Jat et al 2015).

INM practices in grain legume crops help increase yield, improve soil health, and reduce environmental risks. In mid-hill conditions of Khumaltar, INM practices consisting of compost @ 20 t/ha alone and with recommended doses (RD) of chemical fertilizers 30-60-30 N-P_2O_5-K_2O kg/ha produced 24% and 11% higher grain yield as compared to RD only in soyabean (Neupane et al. 2021). Likewise, in high hills under a wheat-bean (*Phaseolus vulgaris*) cropping system, wheat produced the highest grain yield (2,490 kg/ha) using chemical fertilizer @ 140-65-40 N-P_2O_5-K_2O kg/ha + FYM 6 t/ha, which was 60% higher than the control (no chemical fertilizer). In the case of common bean, a significantly higher grain yield (1,490 kg/ha) was obtained from the treatment 140-75-55 NPK kg/ha + FYM 6 t/ha (Shrestha and Shrestha 2015).

In Terai, INM treatment consisting of 50% RD through poultry manure + 50% through inorganic fertilizers + potato tuber treated with 1% urea and 1% sodium bicarbonate recorded the highest tuber yield (22.86 t/ha) as compared to the control plot (19.55 t/ha). Similarly, net return (NRs. 130,245 per ha) and benefit-cost ratio (1.23) was the highest in INM treatment consisting of 50% RD through poultry manure + 50% through inorganic fertilizers. It is concluded that the integration of different organic and inorganic fertilizers can greatly contribute to the yield of potatoes (Kafle et al. 2019). In inner Terai, the curd yield of cauliflower was significantly higher (12.85 t/ha) when 50% nitrogen was applied from RD and 50% from vermicompost. In that experiment, 50%, 25%, and 25% nitrogen were applied from RD, vermicompost, and FYM, respectively which produced 12.50 t/ha curd yield, while the lowest yield (7.28 t/ha) was recorded when 100% nitrogen was applied through chemical fertilizer (Neupane et al 2020). In tomato, integrated application of FYM 16.66 t/ha along with 8.33 mt/ha vermicompost and recommended dose of NPK produced the maximum fruit yield (25.74 mt/ha) in mid hills (KC and Bhattarai 2011).

5.4.2 Site-specific nutrient management in a rice-wheat cropping system

Site-specific nutrient management (SSNM) is a plant need-based approach for applying major nutrients NPK at optimal rates (IRRI 2006) and it depends on crop nutrient requirements based on economically efficient yield targets, the inherent capacity of soil to supply nutrients, and plant N status during the critical period of growth to optimized fertilizer N efficiency (Dobermann and white 1999).

The National Soil Science Research Center (NSSRC) under NARC, in collaboration with Feed the Future Nepal Seed and Fertilizer Project has recently launched site-specific fertilizer recommendations for rice, maize, and wheat in Nepal. Previously, Nepal had implemented the blanket approach of fertilizer recommendations developed four decades ago assuming the entire country as a domain despite the heterogeneity of soils, other biophysical conditions, and agronomic management practices, including crop variety. The amount of nutrients recommended for a particular crop was the same for the three major, but diverse, geographic regions – the terai, hills, and mountains. In the rice-based cropping system of Terai, SSNM increased the yield up to 35.25% as compared to the Farmers' fertilizer practice (Marahatta 2017).

Leaf color chart (LCC): The leaf color chart (LCC) is used to determine the nitrogen fertilizer needs of rice and wheat crops. Crop requires 16 nutrients including nitrogen, phosphorus, potash, and sulfur that are required in large quantities, and even among these, the nitrogen requirement of rice and wheat is higher. The nitrogen management method using a leaf color chart falls under site specific nutrient management method. In this method, it is identified whether the plant needs fertilizer or not by using a leaf color chart. This method is very simple and very easy and less expensive for farmers to use. This chart has 4 to 6 sheets of light green to dark green color, with which we have to match the color to the leaves of rice and wheat. The following are the different steps of using LCC for rice crops:

- Use leaf color chart after 15 days of planting of rice and until flowering stage;
- The reading should be taken between 8 am to 10 am and 2 pm to 4 pm;
- At the time of taking reading, the sunlight should be behind the person taking the reading so that the sunlight does not fall on the leaf color chart and rice leaf;
- The person taking the reading should be the same person from beginning to end. So, there will be no difference in data;
- While taking the readings, at least 10 plants should be selected from different locations to represent the entire area;
- Place the middle part to the fully developed leaves of 10 selected plants on the color chart and match the color of the leaf color chart;
- If the reading of 6 out of 10 plants falls below 4 then 25 kg nitrogen per ha should be used;
- Reading should be taken every 10 days.

Gaire et al (2021) reported a 55.5% additional grain yield of wheat from using no tillage, residue incorporation and fertilizer application based on LCC as compared to conventional tillage, no residue and fertilizer based on farmers' practice. Similarly, LCC casused 0.3 t/ha additional yield of rice due to improved nitrogen management of rice as compared to using three split applications of nitrogen (Marhatta 2017). Khanal et al (2022) reported higher B: C ratio of wheat production using LCC reading of 5 or less. NRRP, Hardinath conducted research in rice-wheat cropping system which has shown promising result (Table 18). This method had enabled to boost rice yield by 420 kg/ha and lower the requirement of nitrogen by 17 kg over recommended dose in Tejpur, Dhanusa of Nepal (Gire et al 2013).

Table 18. Effectiveness of using LCC in rice productivity and nitrogen use in Dhanusha, Nepal

Place	Fertilizer management	Yield (kg/ha)	Nitrogen (kg/ha)
Tejnagar, Dhanusha	Farmers method	3,980	85
	Recommended dose	4,200	100
	LCC method	4,620	92
Bagara, Dhanusha	Farmers method	4,040	80
	Recommended dose	4,520	100
	LCC method	4,215	95

5.4.3 Improved compost

Basically composting is the breakdown of any organic material (ingredients) into a crumbly dark soil like product in which none of the original materials can be easily identified. Various organic waste materials produced by farming such as husk, effluent, vegetable waste fruit peels, and stubble and so on can be used to produce compost (Fig. 21). Of the various practices of organic recycling for improving soil fertility that of preparing compost from farm residues (either of plant or animal origin) is perhaps the most basic and important. Composting is the sole source of building organic matter in soils. It is pivotal to boost the soil's natural fertility by increasing its share of humus. This can be only done by enriching the soil with organic matter.

Fig. 21. Preparation of improved compost

There are three methods of compost preparation, as follows:

1. House hold composting:

   This method is simple and different from others (passive aerated) as it needs inexpensive preparatory containers and ingredients such as vegetable refuses, fruit peelings, scraps and garden twigs and stubbles of flowers.

2. Composting aided by cattle manure, oilseed cake and clean burnt ash:

   The decomposer genera being attained through oil seed cake and ash mixed thoroughly and embedded inside the wooden box ventilated from three sides with a jute sack inside and again the whole with plastic sheets. As shown in the picture posts, the three ingredients are mixed and watered in the ratio 900:50:50 kg each.

3. Invasive and bulky material based composting:

   Endeavors to prepare compost utilizing invasive plants like *Tithonia spp.,* sunflower, tomato twigs, and moist sawdust and cowdung as an accelerator in the process where the system is operating very well as shown in picture. The greens and browns proportions are maintained so as to give the C: N> 25.

5.4.4 Improvement of farmyard manure

Nepalese agriculture in general integrates crop and livestock production. It is particularly true for high land mix farming system where farmers are practicing integrated farming systems with crops, livestock, forestry, and grassland. The farmyard manure (FYM) is somewhat casually managed that the bedding materials being laid haphazardly, heaped uncovered in the open, and spread when convenient (Biswakarma et al 2015). These practices lead to oxidation, mineralisation, volatilisation, leaching, and erosion, which combine to reduce the quality of the FYM before it is incorporated into the soil, and nutrients are lost. Sustainable Soil Management Programme (SSMP) under NARC, the ICIMOD, and other institutions have supported FYM improvement in mid hills of Nepal.

FYM has important role in maintaining soil fertility and crop productivity particularly in hill farming system because availability and sustainability of chemical fertilizer is always challenging. There are many recommendations for cattle shed management and FYM improvements, however, use of local materials (bamboo based) for the storage of FYM is sustainable. Vista et al (2007) conducted an experiment in eastern mid hill and found significant improvement in nutrient composition in FYM as compared to farmers' management practices. They found 0.98% of total nitrogen when FYM was kept in an aerated bamboo structure (Fig. 22) and treated with agriculture lime @ of 10 gm/ 5 liter of water incorporated at 15-day intervals for 3 months.

Fig. 22. FYM improvement structure based on local resources

5.4.5 Crop diversification and intensification

Maize based intercropping

Maize is the major food crop in the mid-hills of Nepal, however, it is cultivated from Terai to high hills. In maize-based inter/mixed cropping, many vegetable and food crops are grown (Fig. 23). In general, maize-based vegetable intercropping is practiced in Terai while vegetables, ginger, and millet are intercropped in low to mid-hills. Maize and potato intercropping is a predominant cropping pattern in upper mid to high-hills, however, cole crops (cauliflower, cabbage) along with radish are also gaining popularity. In this system, the recommended crop geometry of sole maize (75 cm x 25 cm) is modified to 100 cm x 25 cm (single plant per hill) or 100 cm x 50 cm (2 plants per hill).

Maize vegetable intercropping

Similarly, the highest land equivalent ratio (LER) was recorded from Maize + Lentil-2 (1.839) and Maize + Lentil-1 (1.790) followed by Maize + Potato-2 (1.656), Maize + Potato-1 (1.608), Maize + Pea-2 (1.557) and Maize + Pea-1 (1.344) (NMRP 2015).

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Fig. 23. Maize and vegetable/ginger intercropping in maize based cropping system

Rice based intercropping

Intercropping with rice is not a popular practice in Nepal. Mono cropping of rice in upland rainfed is risky due to the low inherent fertility of soil and lack of adequate rainfall. Combined cultivation of short/long duration leguminous crops with upland rice not only reduces the risk of crop failure but also improves soil fertility conditions. NRRP verified rice + groundnut and rice + maize under farmers' managed conditions in uplands. Statistically, the grain yield of rice was not much different in all the combinations. However, the highest grain yield (2,610 kg/ha) was recorded in the rice + maize combination. Among the intercrops, maize produced the highest grain yield (2,200 kg/ha), rice equivalent yield (2,750 kg/ha), and total rice yield (6,250 kg/ha) (NRRP 2011).

Wheat based mixed/intercropping

Mixed or intercropping of legumes and oilseed crops with wheat is a common practice from Terai to mid-hills in Nepal. This system of crop intensification saves farmers from drought and crop failure mainly in rainfed upland cropping systems. Legumes crops do not compete for nutrients with companion crops because they fix atmospheric nitrogen in their nodules and increase soil fertility. The inclusion of legumes in mixed cropping helps in maintaining soil fertility in addition to the high price of legume produce to the farmers. This is nutrient-smart technology.

Similarly, growing mustard with wheat reduces intra-specific competition and increases total productivity by efficient utilization of available growth resources above and below ground having different root systems. Similarly, in lentil + linseed and mustard + pea mixed cropping systems there is better utilization of growth resources due to differences in nutrient requirements by companion crops.

An experiment on crop diversity through mixed cropping of mustard, and pea with wheat was conducted from the Directorate of Agricultural Research, Parwanipur in 2016. In this study, NL 971, ICJ 9704 and Bionex varieties of wheat, mustard and pea were used, respectively. Wheat and mustard combination provided the highest wheat equivalent yield, as shown in Table 19 (RARSP 2017).

Table 19. Wheat equivalent yield of different combinations of wheat and oil or legume crops in Tarai of Nepal

Wheat+oil or legume	Seed rate (kg/ha)	Wheat equivalent yield (kg/ha)
Wheat + mustard	120 : 4	4260
Wheat + mustard	100 : 6	4241
Wheat + mustard	80 : 8	3120
Wheat + Toria	120: 4	3026
Wheat + Toria	100: 6	3045
Wheat + Toria	80: 8	2746
Wheat + Pea	120: 30	3667
Wheat + Pea	100 : 40	312
Wheat + pea	80: 45	3411
Wheat as mono-crop	120	2933
Wheat as mono-crop	100	2907
Wheat as mono-crop	80	2469

Inclusion of grain legume or oilseed crops as inter or mixed crop with wheat increases the total production, enhance food and nutritional security, crop intensification and diversification and sustainable soil management (Ghimire et al 2016). At Dasharathpur (under river basin area of mid hill of Nepal) in the Sudurpaschim province, among the combinations of wheat, oil and legume crops, wheat + chickpea (50% seed ratio) mix cropping was found profitable with maximum wheat equivalent yield (4,518 kg/ha) and gross return (Rs 112,950/ha). Similarly, mix cropping system of wheat with pea and mustard was also found profitable than sole wheat crop in Surkhet condition. Therefore, mix cropping system either with mustard, pea and chickpea with 50% or 66% seed ratio is recommended for Bheri river basin area for increasing the net productivity per unit area (ARSS, 2012). The details of crop combinations, wheat yield and gross return is presented in Table 20.

Table 20. Yield of wheat under mix cropping of different crops in mid-hill river-basin

Mixed cropping	Wheat equivalent yield (kg/ha) (mean of 3 years, 2010-2012)	Gross return* (Rs/ha) (mean of 3 years, 2010-2012)
Sole wheat (120 kg/ha)	3,637	90,925
Sole pea (40 kg/ha)	3,524	88,100
Sole chickpea (40 kg/ha)	1,311	32,775
Sole mustard (kg/ha)	3,266	81,650
66% pea + wheat (100 kg/ha)	4,105	102,625
66 % chickpea + wheat (100 kg/ha)	3,525	88,125
66 % mustard + wheat (100 kg/ha)	4,062	101,550
50 % pea + wheat (100 kg/ha)	3,830	95,750
50 % chickpea + wheat (100 kg/ha)	4,518	112,950
50 % mustard + wheat (100 kg/ha)	3,653	91,325

* Price: wheat Rs. 25, pea Rs. 80, chickpea Rs. 80 and mustard Rs. 90 per ha

Mixed cropping of oilseed crops (linseed) and legume (lentil)

An experiment of mix cropping of linseed with lentil was conducted from the Directorate of Agricultural Research, Parwanipur, in 2016. Different seed rate combinations of these crops were tested (Table 21). The combination of linseed 20 kg/ha + lentil 40 kg/ha (ratio 1:3) produced the highest lentil yield while linseed 30 kg/ha + lentil 40 kg/ha (ratio 1:1) provided the highest linseed yield (Table 21). The results indicated that mixed cropping was more profitable as compared to sole cropping.

Table 21. Effects of mixed cropping systems on the yield of lentil and linseed in Terai region

Treatments	Seed rate (kg/ha)	Ratio	Lentil yield (kg/ha)	Linseed yield (kg/ha)
Linseed + lentil	20 + 40	1:1	753.5	623.3
Linseed + lentil	20 + 40	1:3	876.6	461.1
Linseed + lentil	25 + 40	1:1	832.4	708.4
Linseed + lentil	25 + 40	1:3	845.7	351.4
Linseed + lentil	30 + 40	1:1	783.1	710.6
Linseed + lentil	30 + 40	1:3	776.4	434.4
Linseed	25 (linseed)	Mono	778.5	505.5
Lentil	40 (lentil)	Mono	741.4	503.7

Intercropping/mixed of mustard and pea

An experiment was conducted to find out the optimum combination of two seed rates of mustard (6 and 8 kg/ha), two seed rate of pea (45 and 30 kg/ha) and two planting method, mixed and planted in alternate row 30 cm apart along with sole crop for higher profit at the farm of the Directorate of Agricultural Research, Parwanipur, Bara during 2016. Different seed rate combinations of these crops were tested (Table 22). The highest seed yield of mustard was recorded from the combination of mustard 6 kg/ha + pea 30 kg/ha (alternate cropping) (469 kg/ha) while in case of pea, the yield was highest in the combination of mustard 8 kg/ha + pea 45 kg/ha (alternate cropping) (253 kg/ha).

Table 22. Effects of mixed and intercropping of mustard and pea on their yield in Terai condition of Nepal

Treatment	Seed rate (kg/ha)	Mustard yield (kg/ha)	Pea yield (kg/ha)
Mustard + pea (mixed)	6 + 30	386	194
Mustard + pea (mixed)	8 + 45	287	199
Mustard + pea (alternate)	6 + 30	469	226
Mustard + pea (alternate)	8 + 45	2200	253

5.4.6 Conservation Agriculture

Conservation Agriculture (CA) is an approach to managing agroecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (Karki and Shrestha 2015). The three principles of conservation agriculture are minimum mechanical soil disturbance, residue retention, and suitable crop rotation (FAO 2022).

In CA based experiment, it was reported that rice yield was higher in no tillage (6.64 t/ha) and residue incorporated level (7.02 t/ha) in comparison with conventional tillage (5.39 t/ha) and residue removed level (5.02 t/ha) (Dahal et al 2014). Similarly, maize and rice under no-tillage and residuce maintained with recommended doses of nutrients recorded higher yield compared to conventional rice-maize cultivation practices (NMRP 2016). CA was also found effective in managing lodging problem on maize.

In mid-hill condition, CA based practices [zero tillage + residue kept + maize intercropped with soybean followed by wheat (M+S)-W] provided the highest net benefit (NRs. 109,317) followed by ZT (zero tillage) + RR (residue removed) + (M+S)-W (NRs. 103,185) (ARSP 2014). In mid hill condition of Khumaltar, in maize-rice cropping system, zero tillage practices produced 22% higher grain yield (6.55 t/ha) as compared to conventional tillage (5.14 t/ha) (AGD 2017). In Terai condition of Bhairhawa, significantly higher grain yield of wheat was obtained under total residue (2.49 t/ha) as compared to partial (2.27 t/ha) and zero residue (2.14 t/ha) (NWRP 2016). In the same location, wheat variety Vijaya provided 3% more yield under crop residue incorporation (NWRP 2017). In rice-wheat cropping system of mid-hill, lentil variety Maheswor Bharati produced the highest grain yield of 1,124 kg/ha when sown with seed drill machine with 30 cm rice straw retention, followed by machine sowing in conventional tilled soil (962 kg/ha) (AGD 2017).

5.4.7 Green and brown manuring

Green and brown manuring is the practice of incorporating legume or non-legume green plants into the soil either grown in-situ or plants grown in other places and cut and incorporated into the soil (Maitra et al. 2018). Rice-wheat cropping system is one of the most important crop production systems in Nepal. After the harvest of winter crops and before planting of rainy season crops (rice) there is sufficient time available for growing short-duration green manuring crops (Fig. 23) like legumes which can improve the fertility of soil by the addition of nitrogen (Gautam et al. 2021). Various crops are used as green manuring crops but Sesbania and Sunhemp are popular due to producing higher organic matter on decomposition. Sesbania (*Sesbania rostrata*) is a leguminous plant having fast growth, root and stem nodulating, hence, a good substitute for N management in rice production and also improve soil health (Naher et al 2019) and it can provide 25% of the N requirement of the crop (Wang et al 2009).

There was a 8.1% increment in the grain yield of rice in the Sesbania green manuring plot over the farmers' practice (control) at the mid-hill condition of the Kavre district. Gautam et al (2021) reported a 71% increment of organic matter in the sunhemp-incorporated plot as compared to only the chemical fertilizer-treated plot in the western Terrain condition of Khajura. Kandel et al (2020) reported that Azolla is a supplementary alternative source of nitrogen fertilizer and it can increase rice yield by 12-14% without any additional nitrogen fertilizer but it needs a supplement of phosphorus and potassium fertilizer.

Fig. 24. Growing dhaincha (*Sesbania rostrata*) for green/brown manuring

Brown manuring involves seeding of direct seeded rice and Sesbania crops together and killing the Sesbania at 25-30 days after seeding by the application of post-emergence herbicide 2,4-D ethyl ester at the rate of 0.50 kg/ha (Singh et al 2007). Due to this herbicide green leaves of Sesbania turns into brown color, so, called brown manuring (Fig. 24). It also decreases the weed population by restricting the growth of weeds at initial stage while in later stages by shading effect. This also add about 15 kg N/ha with conserving soil moisture (Gaire et al 2013) and decrease the population and biomass of weeds up to 41-56% and 62-75%, respectively as compared to crops without brown manuring (Nawaz et al 2017). Experiments based on green manuring and brown manuring in rice conducted in Nepal showed that green/brown manuring produced significantly higher grain yield than the control plot. Brown manuring with Crotolaria produced a significantly higher yield (3.23 t/ha) in the Chitwan condition (Gaire et al 2013). Shah et al (2020) reported that Sesbania knockdown at 35 DAS seems better for a higher yield of dry direct seeded rice.

4.4.8 Biochar

The decreasing soil fertility in developing countries including Nepal is a serious issue which demands immediate attention. Biochar technology has emerged a to be a solution for this problem (Bhattarai et al. 2015). Biochar is a carbon rich product (Fig. 25) obtained by pyrolysis in which biomass such as wood, manure or leaves of plant are heated at relatively low temperatures (< 700^{0}C) in a closed container with little or no available air (Baboloal et al 2020). It is used as soil amendment and has potential to boost soil fertility by increasing water and nutrient holding capacity, improving cation exchange capacity, maintaining soil pH and increasing the activity of soil microorganisms (Lehmann et al. 2006). It also contributes to Carbon sequestration (Woolf et al 2010). When biochar is applied with other nutrient sources is becomes more productive (Wang et al 2014). Biochar application was found to be effective in improving soil bulk density, pH, soil organic matter and soil nitrogen and potassium content (Pathak et al 2022).

Fig. 25. Biochar as a source of soil nutrient

In chitwan condition under maize-mustard relay cropping, recommended dose of fertilizer and FYM along with biochar @ 5 t/ha provided the highest maize yield (3.03 t/ha) (NMRP 2017). In Terai condition (Rupandehi) of Lumbini province, biochar alone increased the root yield of radish by 12%, 31.2% and 43% at 5 t/ha, 10 t/ha and 15 t/ha, respectively, as compared to the control treatment (0 t/ha) (Pathak et al. 2022). Similarly, in eastern Terai, Dhahal et al. (2021) recommended the use of biochar and cattle manure mixtures to increase the radish root yield. In mid-hill condition of Sardikhola, Kaski, mineral fertilizer mixed with biochar @ 2 t/ha recorded significantly higher curd yield (44.23 t/ha) of Snow-Mystic variety of cauliflower followed by mineral fertilizer mixed biochar @ 1t/ha (37.62 t/ha) as compared to 18.2 t/ha from control/ farmer's practice (Timilsina et al. 2020).

5.4.9 Permanent bed planting

Permanent beds (Fig. 26) help in improving soil health avoiding soil puddling. Permanent bed is more profitable in rice-wheat-legume cropping pattern. In Rice-Wheat-Moong bean system in Birgunj (Madhesh Province), the highest rice grain yield of 5,409 kg/ha was recorded in permanent bed with direct seeded rice and mulching (wheat straw @4 t/ha) and lowest of 4,910 kg/ha in flat planting without mulching. Similarly, the highest wheat grain yield of 3,657 kg/ha was received in bed planting with mulching (rice straw @ 4 ton/ha) and lowest of 2,644 kg/ha in flat planting without mulching. The highest moong bean grain yield of 507 kg/ha was recorded by bed planting with mulching (wheat straw @4 t/ha). Hence, the bed planting method with mulch was the best in the rice-wheat-moong bean cropping system (AIRC 2021). For the promotion of this technology, large demonstration plot trials, visit programs and subsidy on equipment should get priorty.

Fig. 26. Permanent bed planning

5.5. Knowledge smart CSA technologies

5.5.1 Sowing/planting time adjustment

Timely seeding or planting of crop is necessary to uniform germination, better stand against weeds and other pests, fast growth, healthy plants and higher yields. The best time to plant depends on locality, variety, weather, water availability and the best harvest time (www.knowledgebank.irri.org). The sowing/planting time of major crops are discussed below.

Planting time adjustment in maize has significant implication on yield increment. The usual planting time is for winter season maize in Terai and inner Terai of Nepal is 15 August to 15 October. However, the 25th August planting was reported to give higher yield of maize in two varieties - Rampur Composite (8.49 t/ha) and Arun-2 (6.7 t/ha) (Bhandari et al 2013). For summer season maize, hybrids RML-86/RML-96 recorded the highest grain yield (3,476 kg/ha) followed by RML-95/RML-96 (3,352 kg/ha) when those varieties were planted in the third week of June (NMRP 2016).

In case of wheat, November seeding is the best for yield increment in Terai and inner Terai of Nepal. At Bhairhawa and Nepalgunj, the 25th November sowing produced a higher grain yield (3,729 kg/ha) as compared to 10th November and 10th December sowing. In mid-hills, planting wheat on 10th November produced the highest gain yield (2,887 kg/ha) while yield was reduced with delayed sowing (AGD 2017). Malla et al (2016) reported the 6th November sowing as the best time for higher grain yield of wheat under mid-hill conditions.

In Tarahara condition, seeding of Boro rice on the 30th of November produced a significantly higher grain yield (2.4 t/ha) as compared to the 20th of November and 10th of December seeding (RARST 2015). In DSR, the highest grain yield (6,142 kg/ha) was observed when rice was sown on the 5th June and after the 20th June the yield was drastically reduced (AGD 2017). In the case of transplanted rice, a significantly higher grain yield (6.5 t/ha) was observed when rice seedling was transplanted on the 25th of June in mid hill condition of Khumaltar (AGD 2017). In soybean, the 24th May planting showed the highest grain yield (1,731 kg/ha) as compared to the 2nd June, 11th June, 20th June, and 29th June) (AGD 2017).

5.5.2 Integrated pest management (IPM)

Insect pests are one of the limiting factors in crop productivity worldwide and losses due to various insect pests vary with crop, geographical location, and pest management options (Dhawan and Peshin 2009). In IPM, sustainable and scientific decisions are made which include biological, cultural, physical, and chemical tools to identify, manage, and minimize the risk associated with pests. Pest management tools and strategies are made to minimize the economic, health, and environmental risks (USDA-ARS 2018). It is an approach to managing pests in an economically viable, socially acceptable, and environmentally safe manner (Dara 2019).

In Nepal, IPM was started in 1997 with the Community IPM Support Program with financial support from FAO (Thapa 2017). IPM is upscaling through the Farmers Field School (FFS) approach. Many IPM technologies are developed and recommended in Nepal.

5.5.3 Home garden

To fulfill the basic needs of the household different varieties of vegetables, fruits, medicinal plant species, fodder trees, plants with important traditional and cultural values, and livestock are managed around the household is called a home garden. Home garden is not a new agriculture system, rather it is a traditional agriculture practiced by Nepalese farmers. It is an important nutritional resource for the poor farmers. Climate-resilient gardening could be promoted in the following ways:

- Minimum tilling;
- Growing perennial plants;
- Avoiding chemical fertilizer- Use compost and natural amendments;
- Avoiding pesticides- Follow organic and ecological methods;
- Maintaining plant diversity-polyculture plants, crop rotation, plant edible, herbs, and flowers in the same bed;
- Planting native plants;
- Creating microclimate.

5.5.4 Integrated fish farming

Integrated fish farming is a sustainable agriculture technology that involves an integration of agricultural production (livestock and/or crops) with aquaculture, and on-farm waste recycling. Integrated fish farming is one of the best examples of mixed farming. Possible combinations include fish and poultry, fish and pig, fish and duck, fish and cattle, and fish and goat or sheep. Integrated fish farming plays a major role in increasing its resilience to climate change.

Combination of poultry duck, pig, and fish farming

Different indigenous and exotic poultry and swine breed can be reared by in-shed built above the pond in which poultry and swine droppings and feed waste are utilized by the fish. Ducks are commonly called biological aerators and they also control the aquatic insect's molluscs and weeds. However, its area coverage is meager in Nepal.

Rice cum fish farming

Rice cum fish farming is a method of intergraded farming technology in which late maturing non-lodging and water logging rice varieties are planted in a 20 - 25 cm distance and the fingerlings are stocked after 15 days after rice plantation. Common carp and tilapia fish can be cultivated by this method and in this type of farming, there is minimum use of chemical fertilizer. Rice cum fish farming is an example of mutual benefit as these fish eat algae and help in the mineralization of organic matter which increases soil fertility and increases paddy production. A trench of 50 cm width and 30 cm depth (MOALD 2019) should be constructed at the periphery of the field as a refuse during high temperatures, and low water levels, and to protect from predators.

Rice-cum-fish culture can play an important role in Nepal with the production of rice and fish protein and at the same time achieving food security, poverty alleviation, and sustainable economic development. Due to the zero application of chemical fertilizer, it is also called environment-friendly farming.

The suitable rice varieties for rice cum fish farming in Nepal according to the government of Nepal (MOALD 2019) are listed below:

▪For hilly region: Chandina, IR-36, IR-42, Ir-52, IR-54

▪For terai region: Bindeshwari, Chandina, Barkhe-2,

Hilly region : IR-36, IR-42, Ir-52, IR-54

Terai region : Bindeshori, Chandina, Barkhe-2, Barkhe-4, IR-9727

Other varieties : Panidhan, Tulas, CR 2300, Radha- 4, Janaki, Mansuli, sabitri.

Besides rice cum fish farming, LIBIRD (2022) evaluated integrated rice-duck farming in Kanchanpur and found beneficial to the farmers. The farmers are happy with this type of farming practice since it has increased paddy production by 35%. This technology reduces the production cost compared to the traditional method and it adds organic manure to rice soil. In rice duck farming, agriculture and livestock technicians are required to orient farmers on planting paddy, planting of pulses and vegetables in the bund, management and selection of ducklings, and selection of suitable fields for cultivation. This technology has been more successful for the Tharu communities of the Terai region compared to the other communities. It is a suitable technology to produce organic paddy at a low cost and small farmers can also adopt this technology very easily.

5.5.5 Agro-met advisories

In Nepal, the adoption of improved technologies is too slow to counteract the adverse impacts of varying environmental conditions and climate fluctuations. It is a proven fact that judicious application of meteorological, climatological, and hydrological knowledge and information, including short to long-range forecasts, greatly assist the agricultural community to develop and operate sustainable agricultural systems and increase production in an environmentally sustainable manner.

Nepal's agriculture has been largely dependent on the weather and the vagaries of the monsoon in particular. Uncertainties of weather and climate pose a major threat to the food security of the country. Extreme weather events like heavy rains, indirect impact of cyclones, hail storms, dry spells, drought, heat waves, cold waves, and frost cause considerable losses in crop production every year. An efficient use of available climatic resources, besides soil and water resources, could minimize the adverse effects of extreme weather and take advantage of favorable weather. Such weather services provide a very special kind of input to the farmer as advisories that can make a tremendous difference to agricultural production. So, agro-met advisory service is very important in Nepal.

The analyses of past climate data are especially useful for planning decisions. Weather and short-term forecasts are used in making daily operational decisions. Current and past weather conditions in a specific agricultural area and crop type are useful for the predictions of yield and the incidence of pest and disease potential. Medium and long-range weather forecasts, coupled with past climatological data, are valuable for long-term planning decisions related to crop decisions.

NDRI and CCAFS launched a program in 2014 to disseminate the weather-based agro-advisories in Rupandehi district in coordination with DHM, NARC, and the former DOA. Only the past weeks' weather information on temperature and precipitation were used for generating the agro-advisories. In 2015, NADRI under the project strengthening generation and climate-based agro-advisory services to smallholder farmers in South Asia prepared 17 issues of the weekly agro-met advisory bulletin for the farmers of Dhanusha district. NARC prepared the bulletin from 26 January to 25 May 2015 on every Monday. The weather forecast was provided by Skymet Weather Services Pvt. Ltd., India.

NARC, in collaboration with the Department of Hydrology and Meteorology (DHM), started the agro-met advisory bulletin service to the farming community in 2015 under the PPCR: BRCH/AMIS project. The bulletin has been prepared and disseminated on a weekly basis as a pilot for the 25 pilot districts. After the termination of the project (Nov 2019) NARC rolled out the AAB at the national level. Weather statistics of the past week are provided by the Agro-met Section whereas the weather outlook for the coming week is provided by the Meteorological Forecasting Division (MFD) of the DHM. Seasonal outlook as well as special weather alerts provided by the DHM is also considered in the preparation of the advisory. The expert team analyzes the problems faced by the farmers, reported on the Kisan Call Centre conducted by the National Agricultural Technology Information Centre (NATIC), as well as weather statistics and the outlook for the generation of advisories. The bulletin has been disseminated through the Google group, email, website, mobile app, television, and SMS services.

In collaboration with the Agriculture Knowledge Centre (AKC) in Chitwan ICIMOD prepared the bi-weekly agro-advisory based on on-ground crop conditions information and climate/ weather information provided by the Department of Hydrology and Meteorology and other climate information platforms in 2021. The digital tools developed under this pilot can be easily customized for alignment with agricultural extension services in all our RMCs. The data collected on crop diseases and pests from the pilot can be used to train machine-learning algorithms to track and predict crop diseases and pest outbreaks in the future. Gandaki Province started preparation of the provincial AAB at a provincial level in collaboration with the DHM and the NARC on 23rd September 2022.

For the timely dissemination of AAB, synergistic collaboration among government institutions is required. Though the reliability of the forecasts issued by the DHM has increased, seasonal and sub-seasonal forecasts should be issued with sufficient time in advance. Provincial-level AAB should be prepared and disseminated on real time basis. In the existing system feedback from the users is very limited but it is very important for the betterment of the product.

5.6 Carbon smart CSA technologies

5.6.1 Agroforestry

Agro-forestry is a form of intercropping that combines agricultural, pastoral, and forestry elements in one area that provides multiple benefits such as fodder, timber, medicinal plants, food, etc. In agroforestry system trees can be planted in rows, grided as contour or dispersed randomly. We broadly distinguish the agri-silvicultural system that combines trees with crops and the silvo pastoral system that combines trees with livestock. If all these three elements, tree, crop, and animals are combined it is called an agro-silvo-pastoral system. Agroforestry trees are the most important source of fodder for livestock and the farming system in Nepal relies on forests and trees for sustainability (Avis 2018).

It is a climate-smart production system and is considered more resilient than mono-cropping (Charles et al 2014; Haile et al 2014). Agroforestry contributes to climate change mitigation by sequestering carbon and supporting adaptation by reducing heat stress for crops or by diversifying smallholder farmer's income. Agroforestry is nowadays a major component of landscape restoration incentives and it plays a key role in the fight against climate change. All plants in the agroforestry system sequestrate carbon dioxide from the atmosphere. Woody perennials can capture more per unit area and store it longer than annual crops. Good agriculture must accompany agroforestry systems for adaptation to climate change. For better results, farmers are advised to:

- Plant leguminous trees, use green manure, mulching and optimize fertilizer use that enhances soil fertility and moisture retention and reduces the need for irrigation and chemical fertilizer;
- Plant trees and shrubs in line to prevent erosion;
- Plant shade trees to improve the microclimate to reduce heat stress for crops and livestock and mitigate drought.

Some of the agroforestry systems and practices adopted in Nepal (Banko Janakari, Vol 31 No.

I. Horti-agriculture:

- Maize with mango and banana plant;
- Maize along with Pear trees and seasonal vegetables;
- Vegetables and seasonal crops and under orange trees;
- Coffee under walnut jackfruit trees, banana and orange;
- Agricultural crops along with Zanthoxylum armatum (shrub) and orange trees.

II. Agri-silviculture:

- Tea under Alnus nepalensis;
- Cardamom under A. nepalensis;
- Broom Grass (Thysanolaena maxima) along with cardamom, Elaeocarpus;
- Schima wallichii, A. nepalensis, ganitrus and fodder tree species;
- Coffee plants and cardomom under A. nepalensis;
- Coffee plants under multipurpose tree species;
- Seasonal vegetables, maize, and coffee plants under E. ganitrus;
- Agricultural crops along with Cinnamomum tamala;
- C. tamala. along with T. maxima;
- Kiwi, Chirato, and Cardamom along with, E. ganitrus and Taxus wallichiana;
- Agricultural crops and tree species along with NTFPs.

III. Fodder and fruit–trees along with Agri-silvi-horticulture NTFPs

IV. Agro-silvopastoral:

- Fodder trees and livestock along with T. maxima;
- E. ganitrus and banana plants along with Cardamom and C. tamala.

V. Homegarden fruit-trees, seasonal vegetables along with multipurpose trees.

VI. Horti-silvipastoral:

- Z. armatum and Swertia chiraita along with fodder and fruit–trees;
- Fodder trees, multipurpose trees, grasses, and fruit–trees, along with livestock.

VII. Silvopastoral

- *S. wallichii*, *Ziziphus budhensis*, *F. semicordata*, *Litsea monopetala*, and grasses along with goat farming

5.6.2 Fodder management

In the mid-hills and high mountain ranges, cattle, buffalo and goats are particularly vulnerable to climate changes and livestock production is facing challenges due to increased water stress, temperature changes, and reduced fodder availability. Therefore, good husbandry practices such as improved feed and fodder management via increased production, processing, and storage of fodder should be adopted for improving the production and productivity of livestock in Nepal.

Methods of fodder management

Depending on the available forage resources and the weather conditions, fodders and grasses can be preserved either as hay (dry fodder) or as silage (wet fodder). During the rainy season, there is a surplus production of forage that can be preserved (by hay and silage making) for feeding livestock during the lean period. While making silage and hay the following points should be considered:

- Selection of forage suitable for hay and silage;
- Right stage for cutting forage grasses;
- Drying and moisture content of forage grasses.

Hay making

Leguminous plants, which are a major source of protein, can be conserved as hay for feeding in later days. The principle of hay-making is to reduce the moisture content in the green forages sufficiently so as to permit their storage without spoilage or further nutrient losses. The moisture concentration in hay must be less than 15% at storage time. Green forage with thin steam and many leaves is suitable for hay making. For example: oats, berseem, lucern, cocksfoot, dinnanath, seteria, paspalam, molasses, and indigenous forage grass (banso, khar, salimo), etc.

Silage making

Silage refers to any wet and/or green fodder, preserved by organic acids, chiefly lactic acid, that is produced naturally by bacterial fermentation of sugars in the plants under anaerobic conditions. Crops and plant materials are rich in soluble sugars such as sorghum, maize, oats, hybrid napier grass, sugarcane tops, and other grasses that are suitable for silage making. Though silage making with maize plants is common in government and research farms, but it is uncommon in farmer's fields in Nepal. Maize is a common cultivated crop in all three geographical (terai- mountain) regions of Nepal that can be ensilaged in the dent stage. Plastic bag silage with maize can be promoted in Nepal for feeding ruminants as it is easy to prepare and cost-effective.

Feeding is a major constraint to promoting livestock farming in Nepal. To address this issue, a year-round forage crop calendar has been developed and promoted for the farmers of different agroecological regions (Table 23).

Table 23. Year-round forage crop calendar for different agro-ecological zones of Nepal

Name of forage	**Location**	**Date of sowing**	**Seed rate (kg/ha)**	**Time of cutting forage**	**Green mass production (mt/ha)**
Winter forage					
Oats *(Avena sativa)*	Terai/ Mid-hills High hills	Oct-Dec March-May	100-120 100-120	Jan-April	25-50
Berseem (*Trifoliumalexandrinum)*	Terai Mid- hills	Oct-Dec Oct-Dec	100-120 20-25	Dec-Apr Dec-May	70-80 70-80
Vetch *(Vicia sativa)*	Terai / Mid-hills	Sep-Nov	35-40	Dec-Apr	60-70
Cowpea *(Vignasinensis)*	Terai / Mid-hills	Sep-Nov	20-25	Dec-Apr	8-10
Annual Forage					
Teosinte *(Euchlaenamaxicana*	Terai / Mid-hills	Feb-June	35-40	June-Sep	60-80
Sorghum *(Sorghum bicolor)* *(sorghum sudanese)*	Terai / Mid-hills	Mar-June	25-30	June- Sep	25-50
Sudan (hybrid sorghum)	Terai / Mid-hills	Mar-June	10-15	June-Sep	50-80
Bajra *(Pennisetum typhoides)*	Terai / Mid-hills	Mar-June	10-12	June-Sep	50-60
Maize*(Zea mays)*	Terai / Mid-hills	Feb-June	40-50	April-July	50-80
Dinnanath (*Pennisetum pedicilatum)*	Terai / Mid-hills	Apr-June	10-12	June-Sep	80-100

Name of forage	Location	Date of sowing	Seed rate (kg/ha)	Time of cutting forage	Green mass production (mt/ha)
Perennial forage					
Napier *(Penesetum perpurem)*	Terai / Mid-hills	Feb-Apr May-July	1000 sets	May-Dec	120-150
Paragrass *(Barchiaria multicar)*	Terai/low hills	July-Aug	10-15	Apr-Dec	30-60
Seteria *(Seteria SPP)*	Terai / Mid-hills	Apr-July	8-10	May-Nov	30-80
Clover *(Trifolium repens)*	Mid-hills/ High-hills	May-Sep	3-5	Apr-Nov	12-15
Ryegrass *Loliummul tiflorum)*	Mid-hills/ High-hills	May-Sep	10-12	Apr-Nov	10-14
Stylo *(stylosanthes guyanensis)* *(Stylosanthes hamata)*	Terai / Mid-hills	May-July	4-5	Aug-Dec	25-30

Source: National Pasture Fodder Research Program, Khumaltar

5.6.3 Scientific management of grazing land

Out of the total geographic area of 14.7 million hectares about 1.7 million hectares are considered as grassland in Nepal and 98% of the total grassland lies in mid hills and mountains (Pariyar 2008). Grazing livestock in the rangeland is an old practice of farmers in the mountainous region. Pasture/rangelands are rich in diversity and produce a wide variety of goods including timbers, fodder, forage, etc.

Management of grazing land

If the local community uses a quality grazing management system, it is possible to have rapid regrowth of forage in the grazing season. Some of the effective methods for the management of grazing land for mitigation of climate change in Nepal are as follows:

- Identify optimal stocking rate in rangeland;
- Control and systemic grazing;
- Adaptive management practices or silvopasture;
- Reseeding of over-grazed pasture with high-quality legume and non-legume fodders and perennial grasses;
- Introduction of drought-tolerant varieties of grasses;
- Scientific inputs for range owner and user groups such as technical, managerial education, and other assistance program.

Rotational grazing

Frequent movement of livestock through a series of pasture sub-divisions is called rotational grazing and it can be practiced in rangeland and pastureland. Rotational grazing has been implemented in yak, nak, chauri, sheep, goats, cattle, buffalo, and horses in different agroecological climates (Terai-Mountain) of Nepal. It is an effective method of rangeland management where grazed rangeland or paddocks are rested for a certain period to allow the regrowth of vegetative plants. Depending on the forage yield the length of grazing and rest period on rangeland land differs. Transhuman system is an indigenous grazing management practiced by the farmers for centuries in the northern belt of Nepal. Depending upon the forage availability they take their livestock to high alpine pasture during monsoon (June-August) and take them back during the winter (Nov-April).

The advantages of rotational grazing to mitigate climate change are:

- Overgrazing is prevented and pasture is protected;
- Increase forage production;
- Improves organic matter, soil structure, and carbon sequestration;
- Improves soil fertility;
- Reduces cost of production;
- Improves herd health thereby reduce emission;
- Improves drought management.

5.6.4 Cover crop

A cover crop is one of the sustainable agricultural practices that can be adopted by farmers for mitigation and adaptation to the climate crisis. In agriculture, cover crops are plants that are planted to cover the soil rather than for the purpose of being harvested. Cover crops manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity, and wildlife in an agroecosystem managed and shaped by humans. Cover crops may be off-season crops planted after harvesting any cash crop.

Depending on the growing conditions of legume cover crops (crimson clover, red clover, peas, vetch beans) can fix a lot of nitrogen (N) for subsequent crops that reduce nitrogen fertilizer input. Legumes also help prevent erosion, support beneficial insects and pollinators, and they can increase the organic matter content of the soil. According to the type of soil and climatic conditions, the production and adaptability of legumes differ. Non-legumes are useful for scavenging nutrients, controlling erosion, suppressing weeds, and producing a residue that adds soil organic matter. Non-legume cover crops include cereals (wheat, rye, barley, triticale, oats), forage grasses (annual ryegrass), and broadleaf species (mustards, and brassicas, including the forage radish). Incorporation of non-legume residues and legume cultivation has a significant impact on grain, straw, and dry matter yield of succeeding crops.

Cover cropping contributes to the pillars of climate-smart agriculture (CSA) in the following ways:

Table 24: Cover crop contributes to three pillars of CSA

Adaption	Mitigation	Food security
Increases organic matter in the soil Maintains the moisture content of soil and thus, frequency of irrigation is decreased	Reduces carbon emission Reduces the use of herbicide	Increases crop production

6. Conclusions and Recommendations

The Government of Nepal considers climate change as a major constraint or challenge for agriculture and endorses policies for climate change adaptation and mitigation. The Government policies recognize the principles of climate-smart agriculture technologies, increasing productivity and incomes, adapting and building resilience, and contributing to the reduction of greenhouse gas (GHG) emissions. In this inventory report, we have stated those policies and priorities. After discussion at the provincial and farmers' level, we have come up with an exhaustive list of CSA technologies that are being practiced in Nepal.

Nepal has made noticeable progress in developing rice, wheat, and maize varieties adaptable to drought, heat, cold, and submerged conditions. Most of the wheat and maize breeding programs for climate change adaption are focused on Terai, inner Terai/Siwalik hills. In mid and high hills, many minor cereal crops are grown which are the backbone of the food system but have not received due attention from the climate climate change perspectives. In high hills, potato is the major food crop and drought is a critical factor, therefore, drought-tolerant potato varieties should be developed. There have been very limited works on fruit crops in the context of climate change.

Water use efficiency is another important area of adaptation. On the research front, substantial work has been done. However, wider extension and adoption of such smart technologies still require additional efforts. SRI is one prioritized CSA technology taken up by the government of Nepal, but research engagement in various aspects of this technology is still lacking. Drip irrigation is highly adopted by the vegetable growers. AWD irrigation technique is effective and cost-efficient, but adoption of this technology is on a limited scale.

In Nepal, agriculture has more shares in the emission of GHGs followed by the energy sectors. By adopting resource conservation technologies like zero-tillage, fossil fuel consumption in tillage operations can be minimized. It is extensively studied and supported by government schemes; however, the adoption rate is quite low. It is only adopted by a small group of farmers in different Terai districts of Nepal. Upscaling of this technology is very important.

Improvement of soil carbon is a major concern in climate change mitigation. Most of the cereal and vegetable crops are grown using chemical fertilizers. Besides lots of effort in the past, farm yard manure, and compost improvement programs have not achieved considerable success. Sustainable crop intensification is a traditional practice in the hills of Nepal. Due to mechanization in harvesting, mixed/intercropping has been reduced dramatically in the Terai region. Conservation agriculture should be promoted to improve the soil carbon. Green and brown manuring techniques should be scaled up. Some researchers have highlighted biochar but its participatory verification in farmers' fields is required.

Due to climate change, not only the global temperature has been increased, but the pattern of precipitation has also changed. It has impacted on planting and harvesting time of the crops. Some studies related to the sowing/planting times of major cereals have been conducted. A nationwide agro-met advisory has been regularly prepared, however, access to this information to farmers is limited. An automated advisory system should be developed.

There are many climate-smart livestock technologies that Nepalese farmers have traditionally adopted. Nepal has not made significant progress regarding the improvement of traditional CSA technologies in the climate-smart livestock sector. Most of the climate-smart technologies are suitable for the different agro-climatic conditions of Nepal and farmers can adopt it easily. Adoption of these climate-smart livestock technologies on management, feed and feeding, breeding, health, and range land management would reduce the adverse impact of climate change. Further, it will increase production and productivity, reduce methane emissions, improve general health conditions, and protect the environment. A multi-sectoral public-private partnership through CSA-friendly government policy must be in place in order to scale up the CSA technologies in Nepal.

References

Adhikari SP, KP Timsina and J Lamichhane. 2018. Adoption and impact of rain water harvesting technology on rural livelihoods: The case of Makwanpur district, Nepal. Rural Extension and Innovation Systems Journal **14**(1):34-40.

AGD. 2016. Annual Report 2015/16 (2072/73). Agronomy Division (AGD), Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal.

AGD. 2017. Annual Report 2016/17 (2073/74). Agronomy Division (AGD), Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal.

Ahmed M and S Suphachalasai. 2014. Assessing the costs of climate change and adaptation in South Asia. Asian Development Bank. https://www.adb.org/sites/default/files/publication/42811/assessing-costs-climate-change-and-adaptation-southasia.pdf

AIRC. 2021. Annual Report 2020/21 (2077/78). Agriculture Implement Research Center (AIRC), Nepal Agricultural Research Council, Birgunj, Parsa, Nepal.

AIRC. 2022. Annual Report 2021/22 (2078/79). Agriculture Implement Research Center (AIRC), Nepal Agricultural Research Council, Birgunj, Parsa, Nepal.

Ali F, N Kanwal, M Ahsan, Q Ali and NK Niazi. 2015. Crop improvement through conventional and non-conventional breeding approaches for grain yield and quality traits in *Zea mays*. Life Science Journal **12** (4s):38-50.

ARSP. 2014. Annual Report 2013/14 (2070/71). Agricultural Research Station, Pakhribas (ARSP), Nepal Agricultural Research Council, Dhankuta, Nepal.

ARSS. 2012. Annual Report 2011/12 (2068/69). Agricultural Research Station, Surkhet, Nepal Agricultural Research Council, Nepal.

Aryal JP, MB Mehrotra, ML Jat, HS Sidhu. 2015. Impacts of laser land leveling in rice-wheat systems of the north-western indo-gangetic plains of India. Food Security **7**(3):725–738.

Aryal JP, TB Sapkota, DB Rahut, P Marenya and CM Stirling. 2021. Climate risks and adaptation strategies of farmers in East Africa and South Asia. Scientific Reports **11**:10489. **DOI**:10.1038/s41598-021-89391-1

Avis W. 2018. Livelihood options for households in Nepal. https:// opendocs.ids.ac.uk /opendocs/bitstream/ handle/20.500.12413/13593/Livelihood options for households in Nepal .pdf

Balasubramanian V and JE Hill. 2002. Direct seeding of rice in Asia: Emerging issues and strategic research needs for the 21st century. **In**: Direct Seeding: Research Strategies and

Opportunities (S Pandey, M Mortimer, L Wade, TP Tuong, K Lopez, and B Hardy, eds). International Rice Research Institute, Los Banos, Philippines; **pp.** 15–39.

Bastola A, T Karki, S Marhatta and LP Amgain. 2021. Growth, phenology, yield and yield attributes of rice as influenced by tillage, residue and nitrogen management practice in Chitwan, Nepal. African Journal of Agricultural Research **17**(1):128-136. **DOI**: 10.5897 / AJ- AR2020.15168

Belder P, B Bouman, R Cabangon, L Guoan, E Quilang, L Yuanhua, et al. 2004. Effect of water-saving irrigation on rice yield and water use in typical lowland conditions in Asia. Agriculture Water Management 65:193-210.

Bhandari B, DB Gurung and G Bhandari. 2013. Performance of widely adapted maize varieties throughout the year in relation with daily maximum temperature at Rampur, Chitwan, Nepal. YP Giri et al (eds). Proc. 27th National Summer Crops Workshop, 18-20th April 2013, National Maize Research Program, Rampur, Chitwan. Nepal Agricultural Research Council. Volume 1.

Bhatta MR and J Tripathi. 2005. On-station and Onfarm Studies on System of Rice Intensification (SRI). Paper presented Paper presented in SRI Workshop held on 19th December, ICIMOD, Lalitpur, Nepal.

Bhattarai B, J Neupane, SP Dhakal, J Nepal, B Gnyawali, R Timalsina and A Poudel. 2015. Effect of biochar from different origin on physio-chemical properties of soil and yield of garden pea (Pisum sativum L.) at Paklihawa, Rupandehi, Nepal. World Journal of Agricutural Research 3(4): 129-138.

Bhuiyan SI. 1992. Water management in relation to crop production: Case study on rice. Outlook on Agriculture **21**:293-299.

CBS. 2021. Preliminary Result of National Census of Nepal 2078 (2021). Central Bureau of Statistics. https://censusnepal.cbs.gov.np/Home/Details?tpid=1&dcid=0f011f13-7ef6-42dd-9f03-c7d309d4fca3

Chapagain T and A Riseman. 2011. Achieving more with less water: Alternate wet and dry irrigation (AWDI) as an alternative to the conventional water management practices in rice farming. Journal of Agricultural Science **3**(3):3-13.

Chapagain TR, S Piya, JL Mandal and BP Chaudhary. 2010. Up-scaling of polyhouse tomato productiontechnology in mid and high hills of eastern Nepal. In: Proceedings of ninth national outreach researchworkshop (June 7-8, 2010), Kathmandu (MN. Paudel, TP. Barakoti and YN Ghimire, eds). Outreach Research Division, Nepal Agriculture Research Council, Kathmandu. pp. 116-120

Charles RL, EF Nzunda and PKT Munishi. 2014. Agroforestry as a resilient strategy in mitigating climate change in mwanga district, kilimanjaro, Tanzania. Global Journal of Biology, Agriculture and Health Scienc 3(2):11-17

Chhetri NB. 2011. Climate sensitive measure of agricultural intensity: Case of Nepal. Applied Geography **31**(2):808–819.

CIAT; World Bank; CCAFS and LI-BIRD. 2017. *Climate-Smart Agriculture in Nepal. CSA Country Profiles for Asia Series*. International Center for Tropical Agriculture (CIAT); World Bank; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); Local Initiatives for Biodiversity Research and Development (LI-BIRD). Washington, D.C. 26p.

CSISA. 2018. Zero tillage wheat. Training of trainers modules 2018. The Cereal Systems Initiatives for South Asia (CSISA). www.csisa.org

Climate Watch. 2019. Climate Watch, Country Profile Nepal. https:// www. climate watchdata .org/ cou- ntries/NPL.

Dahal KR. 2014. System of rice intensification (SRI): a potential approach to enhance rice productivity and food security. Journal of Forest and Livelihood 12(1):75-81.

Dahal S, TB Karki, LP Amgain and BK Bhattachan. 2014. Tillage, residue, fertilizer and weed management on phenology and yield of spring maize in Terai, Nepal. International Journal of Applied Sciences and Biotechnolgy **2**(3):328-335. **DOI:**10.3126/ijasbt.v2i3.11001

Dahal KR and RB Khadka. 2012. Performance of rice with varied age of seedlings and planting geometry under system of rice intensification (SRI) in farmer's field in western terai, Nepal. Nepal Journal of Science and Technology **13**(2):1-6

Dar MH, SA Waza, S Shukla, NW Zaidi, S Nayak, M Hossain, A Kuma, AM Ismail and US Singh. 2020. Drought-tolerant rice for ensuring food security in eastern India. Sustainability. **DOI:**10.3390/su12062214.

Dara SK. 2019. The new integrated pest management paradigm for the modern age. Journal of Integrated Pest Management **10**(1):1-9. **DOI:**10.1093/jipm/pmz010

Dhawan AK and R Peshin. 2009. Integrated pest management: concept, opportunities and challenges. Integrated Pest Management: Innovation Development Process 51-81. **DOI:** 10. 10 07/978.1.4020.8992.3_2

Dhakal MP. 2005. Farmers' evaluation of the system of rice intensification in the middle mountains of Nepal. Resource dynamics in mountain watersheds of the HKH (PARDYP)/International Center for Integrated Mountain Development (ICIMOD), Khumaltar, Kathamandu, Nepal.

Dhital K. 2011. Study on system of rice intensification in transplanted and direct-seeded versions compared with standard farmer practice in Chitwan, Nepal. A thesis of master of science, Institute of Agriculture and animal science, Rampur, Chitwan, Tribhuwan University.

DHM. 2017. Observed Climate Trend Analysis Report Observed Climate Trend Analysis in the Districts and Physiographic Regions of Nepal (1971-2014). Department of Hydrology and Meteorology (DHM), Kathmandu, Nepal.

DLS. 2020. Annual Report (2019/2020). Ministry of Agriculture and Livestock development. http://www.dls.gov.np/reportfiles/Livestock%20Statistics%202076_77_1642393389.pdf

Dobermann A and PF White. 1999. Strategies for nutrient management in irrigated and rainfed lowland rice systems. In: V Balasubramanian, JK Ladha and GL Denning (eds). Resource management in rice systems: nutrients. Development in Plant and Soil Science 81. Springer, Dordrecht. DOI:https://doi.org/10.1007/978-94-011-5078-1_1

Edwards W and D Smith. 2005. Iowa custom farm rate survey. Ames: Iowa State University. http://www.extension.iastate.edu/publications/FM1698.pdf).

Evans C, S Justice and S Shrestha. 2002. Experience with the system of Rice Intensification in Nepal. In: proceeding of an International Confernecee onAssessment of the System of Rice Intensification (SRI), Sanya, China, Uphoff et al (eds), pp 64-66. http://ciifad.cornell.edu/sri/proc1

FAO (Food and Agriculture Organization). 2010. Climate smart agriculture policies, practices and financing for food security, adaptation and mitigation. The document was prepared as a technical input for the Hague Conference on Agriculture, Food Security and Climate Change, to be held 31 October to 5 November 2010.

FAO. 2005. Livestock Sector Brief. Food and Agriculture Organization of the United Nations.

FAO. 2013. Climate-smart agriculture. Food and Agriculture Organization of the United Nations. http://www.fao.org/climate-smart-agriculture/en/

FAO. 2017. Climate-smart agriculture. Food and Agriculture Organization of the United Nations. http://www.fao.org/climate-smart-agriculture/en/

FAO. 2022. Conservation agriculture. Food and Agriculture Organization of the United Nations. http://www.fao.org/conservation-agriculture/en/

Farooq M, KHM Siddique, H Rahman, T Aziz, DJ Lee and A Wahid. 2011. Rice direct seeding: Experiences, challenges and opportunities. Soil Tillage Research **111**:87-98.

FRD. 2017. Annual Report 2016/17 (2073/74). Fisheries Research Division, NARC, Godawari, Lalitpur, Nepal

Gadal N, J Shrestha, MN Poudel and B Pokharel. 2019. A review on production status and growing environments of rice in Nepal and in the world. Archives of Agriculture and Environmental Science **4**(1):83-87.

Gaire R, KR Dahal and LP Amgain. 2013. Effect of different mulching materials on weed dynamics and yield of direct seeded rice in Chitwan, Nepal. Agronomy Journal of Nepal **3**:73-81.

Gaire JJ, M Adhikari, D Ghimire, A Khatri-Chhetri and D Pandey. 2021. Intervention of climate-smart practices in wheat under rice-wheat cropping system in Nepal. Climate 9:19. DOI: https://doi.org/10.3390/cli9020019

German Watch. 2019. Global Climate Risk Index. 2021. Available online: https://germanwatch.org/en/19777

Gauchan D and D Dongol. 2015. Country report for wheat expert elicitation study, CIMMYT NARC Collaborative Study for Varietal Release and Adoption Data (2014). Strengthening Impact Assessment in CGIAR (SIAC) Project. Nepal Agricultural Research Council (NARC), Kathmandu, Nepal.

Gauchan D, B Sapkota, S Gautam, DB Thapa Magar, B Sharma, S Amatya, S Sapkota, MB Nepali, S Singh and US Singh. 2014. Development and dissemination of stress-tolerant rice varieties in Nepal. IRRI/NARC STRASA Project. Socioeconomics and Agricultural Research Policy Division (SARPOD), Nepal Agricultural Research Council, Nepal.

Gautam R, CP Shriwastav, S Lamichhane and BR Baral. 2021. The residual effect of pre-rice green manuring on a succeeding wheat crop (*Triticum aestivum* L.) in the rice-wheat cropping system in Banke, Nepal. International Journal of Agronomy. **DOI:**10.1155/2021/4142743

Ghimire TB, KR Pokhrel, NS Chettry and GB Pun. 2016. Seed ratio of pea, chickpea and mustard as mix cropping with wheat in Bheri River Basin area of Nepal. YP Giri et al. (eds). Proc. 29th National Winter Crops Workshop, 11-12 June 2014, Regional Agricultural Research Station, Lumle, Kaski, Nepal. Nepal Agricultural Research Council.

Gill GJ. 2014. An assessment of the impact of laser-assisted precision land levelling technology as a component of climate-smart agriculture in the state of Haryana, India.

Giri YP, D Bhattarai, B Joshi, P Paneru, T Paudel, A Raimajhi and B Sapkota (eds). 2016. Krishi Prabidhi Sangraha-4, (2073) Nepal krishi Anusandhan Parishad (in Nepali language).

Giri YP, SK Bagle, RP Ghimire, D Bhattarai and BB Pokhrel (eds). 2017. Krishi Prabidhi Sangraha-5, (2074) Nepal krishi Anusandhan Parishad (in Nepali language).

GoN. 2021. National Adaptation Plan 2021–50: Summary for Policy Makers, **p.** 41. https: // www.preventionweb.net/publication/national-adaption-plan-nap-2021-2050-nepal.

Gorkhali NA and SP Neopane. 2008. Cytogenetic study of indigenous livestock of Nepal. Proc. 7th NASRI, Nepal Agricultural Research Council IPCC (1996). Inter-governmental panel on climate change Climate change-1995. The science of climate change, Cambridge University Press, XII, **p** 572.

Gumma MK, D Gauchan, A Nelson, S Pandey and A Rala. 2012. Temporal changes in rice-growing area and their impact on livelihood over a decade: A case study of Nepal. Agriculture, Ecosystems and Environment **142**:382– 392.

Haile KK, N Tirivayi and W TEsfaye. 2014. Farmers's willingness to accept payment for ecosystem services on agricultural land: the case of climate-smart agroforestry in Ethiopia. Ecosystem Services 39:100964. DOI: https://doi.org/10.1016/j.ecoser.2019.100964.

Howell KR, P Shrestha and IC Dodd. 2015. Alternate wetting and drying irrigation maintained rice yields despite half the irrigation volume, but is currently unlikely to be adopted by smallholder lowland rice farmers in Nepal. Food and Energy Security 4(2):144-157. DOI: 10.1002/fes3.58

ICIMOD. 2008. Natural resource management approaches and technologies in Nepal: Technology-System of rice intensification.

IFPRI. 2009. Annual Report. International Food Policy Research Institute. http://ifpri.org

Ilic ZS, L Milenkovic, L Sunic and E Fallik. 2011. Effect of colored shade nets on plant leaf parameters and tomato fruit quality. Journal of the Science of Food and Agriculture **95**:2660-2667.

IPCC. 2019. Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Geneva: IPCC.

IPCC. 2014. Summary for policymakers. In: Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change CB Field et al (ed). Cambridge University Press, Cambridge, United Kingdom and New York, USA, pp 1–32.

International Rice Research Institute (IRRI). 2006. Site-specific nutrient management. Available from: http://www.irri.org/irre/ssnm/

Jain N, R Dubey, J Singh, M Khanna, H Pathak and A Bhatia. 2014. Mitigation of greenhouse gas emissions with system of rice intensification in the Indo-Gangetic plains. Paddy and Water Environment, 12:355-363.

Jat LK, YV Singh, SK Meena, SK Meena, M Parihar, HS Jatav, RK Meena and VS Meena. 2015. Does integrated nutrient management, enhance agricultural productivity? Journal of Pure and Applied Microbiology **9**(2):1211-1221.

Khadka RB, HP Acharya and N Uphoff. 2014. Performance of landrace and improved rice varieties under the system of rice intensification management in Bajhang district of Nepal. The journal of Agriculture and Environment 15:1-10.

Kafle K, CP Shriwastav and M Marasini. 2019. Influence of integrated nutrient management practices on soil properties and yield of potato (*Solanum tuberosum* L.) in an inceptisol of Khajura, Banke. International Journal of Applied Science and Biotechnology **7**(3):365-369.

Kandel S, R Malla, BH Adhikary and SP Vista. 2020. Effect of Azolla application on rice production at mid-hills condition of Nepal. Tropical Agroecosystems **1**(2):103-106. **DOI:**10.26480/taec.02.2020.103.106

Karki TB and J Shrestha. 2015. Should we go for conservation agriculture in Nepal. International Journal of Global Science Research **2**:271-276.

KC and BP Bhattarai. 2011. Effect of integrated nutrient management on the growth, yield and soil nutrient status in tomato. Nepal Journal of Science and Technology **12**:23-28.

Khanal P, SK Sah, M Acharya, S Marhatta and MP Neupane. 2022. Precision nitrogen management in wheat at Rampur, Chitwan, Nepal. The Journal of Agriculture and Environment **23**:143-155.

Khatiwada KR and VP Pandey. 2019. Characterization of hydro-meterological drought in Nepal Himalaya: a case of Karnali River Basin. Weather and Climate Extremes **26**:100239. **DOI:**10.1016/j.wace.2019.100239.

Koirala KB, YP Giri, TR Rijal, PH Zaidi, AR Dadananda and J Shrestha. 2017. Evaluation of grain yield of heat stress resilient maize hybrids in Nepal. International Journal of Applied Sciences and Biotechnology **4**:511-522. **DOI:**10.3126/ijasbt.v5i4.18774

Koirala KB, YR Pandey and TB Ghimire. 2013. Road-map for development and deployment of heat resilient maize in Nepal. **Paper presented in:** 1st Annual progress review and planning workshop, Hotel Yak and Yeti, Kathmandu, Nepal.

Koirala KB. 2017. Scaling-up of proven technology for maize improvement through participatory approach in Nepal. PR Pandey and KB Koirala (eds). Best Practices of Maize Production Technologies in South Asia. SAARC Agriculture Centre (SAC), Dhaka, Bangladesh: **p**145.

Kumar V and JK Ladha. 2011. Direct seeding of rice: Recent developments and future research needs. Advances in Agronomy **111**:297-413.

Lamichhane K. 2013. Effectiveness of sloping agricultural land technology on soil fertility status of mid-hills in Nepal. Journal of Forestry Research **24**(4):767-775.

Lehmann J, J Gaunt and M Rondon. 2006. Bio-char sequestration in terrestrial ecosystems-a review. Mitigation and Adaptation Strategies for Global Change **11**(2):403-427.

LIBIRD. 2022. http://libird.org

Lipper L and D Zilberman. 2018. A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates. Zilberman et al (eds), Natural Resource Management and Policy. FAO, Rome, Italy.

Mahul O, N Verma and D Clarke. 2012. Improving Farmers Access to Agriculture Insurance. Worldbank Policy Research Working Paper No. 5987. The Worldbank India. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2016752

Maitra S, A Zaman, TK Mandal and JB Palai. 2018. Green manures in agriculture: A review. Journal of Pharmacognosy and Phytochemistry **7**(5):1319-1327.

Malla GS, AK Gautam, A Sharma, A Timilsina and HP Devkota. 2016. Study on wheat at different seeding dates under changing climate parameters at Khumaltar. YP Giri et al. (eds). Proc. 29th National Winter Crops Workshop, 11-12 June 2014, Regional Agricultural Research Station, Lumle, Kaski, Nepal. Nepal Agricultural Research Council.

Marhatta S. 2017. Increasing productivity of an intensive rice based system through site specific nutrient management in western Terai of Nepal. The Journal of Agriculture and Environment **18**:140-150.

Maskey RB. 2003. Options for sustainable land management in the mid-hills of Nepal: experience of testing and demonstration of contour hedgerow intercropping technology. Mountain agriculture in the Hindu Kush-Himalayan region. Proc. International Symposium held in Kathmandu, Nepal, 21-24 May, 2001; **pp.**79-84.

Meena RK, A Vashisth, R Singh, B Singh and KM Manjaih. 2014. Study on change in microenvironment under different colour shade nets and its impact on yield of spinach (*Spinacia oleracea* L.). Journal of Agrometeorology **16**(1): 104-111.

MoAD. 2015. Agricultural Development Strategy of Nepal. Ministry of Agricultural Development, Government of Nepal, Kathmandu, Nepal.

MoALD. 2019. Statistical Information on Nepalese Agriculture 2075/76 (2018/19). Ministry of Agricultural and Livestock Development, Government of Nepal, Kathmandu, Nepal.

MoALD. 2020. Statistical Information on Nepalese Agriculture 2076/77 (2019/20). Ministry of Agricultural and Livestock Development, Government of Nepal, Kathmandu, Nepal.

MoALD. 2022. Statistical Information on Nepalese Agriculture. Ministry of Agriculture and Livestock Development. Planning and Development Cooperation Coordination. Statistics and Analysis Section. Singhadurbar, Kathmandu, Nepal; **p** 274.

MoE. 2010. National Adaptation Programme of Action (NAPA) to Climate Change. Ministry of Environment, Government of Nepal, Kathmandu, Nepal.

MoE. 2011. Climate Change Policy, 2011. Ministry of Environment, Government of Nepal, Kathmandu, Nepal.

MoFE. 2021. Vulnerability and Risk Assessment and Identifying Adaptation Options: Summary for Policy Makers. Ministry of Forests and Environment, Government of Nepal. Kathmandu, Nepal.

MoFE. GoN. 2021. National Adaptation Plan (NAP) 2021 to 2050. Summary for Policymakers. Kathmandu: MoFE. https://unfccc.int/sites/default/files/resource/NAP_Nepal.pdf

MoFSC. 2014. Nepal Biodiversity Strategy and Action Plan 2014-2020. Ministry of Forest and Soil Conservation, Kathmandu, Government of Nepal.

MOI (Ministry of Irrigation, Government of Nepal). 2014. Irrigation Policy, 2013, Ministry of Irrigation, Government of Nepal. http://www. moir.gov.np.

Naher UA, ATMA Choudhury, JC Biswas, QA Panhwer and IR Kennedy. 2019. Prospects of using leguminous green manuring crop Sesbania rostrate for supplementing fertilizer nitrogen in rice production and control of environmental pollution. Journal of Plant Nutrition. **DOI:**10.1080/01904167.2019.1672734

NARC (Nepal Agricultural Research Council). 2007. Released and registered crop varieties in Nepal 1960-2007. Communication, publication and documentation division, NARC, Kathmandu, Nepal.

NARC. 2008. NARC Research Highlights (2002/2003-2006/2007). Nepal Agricultural Research Council, Singhadurbar Plaza, Kathmandu.

Nawaz A, M Farooq, R Lal, A Rehman, T Hussain and A Nadeem. 2017. Influence of Sesbania brown manuring and rice residue mulch on soil health, weeds and system productivity of conservation rice-wheat systems. Land Degradation and Development **28**(3):1078-1090.

NDC. 2020. Second nationally determined contribution (NDC). Government of Nepal, Kathmandu.

Neupane B, K Aryal, LB Chhetri and S Regmi. 2020. Effects of integrated nutrient management in early season cauliflower production and its residual effects on soil properties. Journal of Agriculture and Natural Resources **3**(2):353-365. **DOI:** https:// doi. Org /10.3126 / janr.v3i2.32548

Neupane R, R Amagin and R Shrestha. 2021. Effect of integrated nutrient management in soybean variety Tarkari Bhatmas-1 at Khumaltar condition. Agronomy Journal of Nepal **5**:79-87.

NIB. 2022. Agriculture Insurance data (2020/2021). Nepal Insurance Board. https:// nib.gov.-np/wp-content/uploads/2022/01/Agri-8-Years-Data_up-to-2077_78.pdf

NMRP. 2015. Annual Report. 2014/15 (2071/72). National Maize Research Program, NARC, Rampur, Chitwan, Nepal.

NMRP. 2016. Annual Report. 2015/16 (2072/73). National Maize Research Program, NARC, Rampur, Chitwan, Nepal.

NMRP. 2017. Annual Report 2016/17 (2073/74). National Maize Research Program, NARC, Rampur, Chitwan, Nepal.

NPC and WFP. 2019. The Food Security Atlas of Nepal. Kathmandu, Nepal. https://npc.gov.np/images/category/Food_Security_Atlas_2019.pdf

NRRP. 2011. Annual Report 2010/11 (2066/67). National Rice Research Program, Hardinath, Dhanusha, Nepal.

NRRP. 2015. Annual Report 2014/15 (2071/72). National Rice Research Program, Hardinath, Dhanusha, Nepal.

NWRP. 2016. Annual Report 2015/16 (2072/73). National Wheat Research Program, NARC, Bhairahawa, Rupendehi, Nepal.

NWRP. 2017. Annual Report 2016/17 (2073/74). National Wheat Research Program, NARC, Bhairahawa, Rupendehi, Nepal.

Pal BD, A Kishore, PK Joshi and NK Tyagi. 2019. Climate smart agriculture in South Asia. DOI:10.1007/978-981-10-8171-2.

Pandey BP, N Khatri, KR Pant, M Yadav, M Marasini, GP Paudel and M Bhatta. 2020. Zero-till wheat (*Triticum aestivum* L.): A Nepalese perspective. Fundamental and Applied Agriculture **5**(4):484-490. **DOI:**10.5455/faa.109442

Pandey S and L Velasco. 1999. Economics of alternative rice establishment methods in Asia: a strategic analysis, Social Science Division Discussion Paper, International Rice Research Institute, Los Banos, Philippines.

Pandey YR and BN Chaudhary. 2004. Evaluation of tomato varieties and their planting dates for commercial production under Jumla agro-ecological condition. Kathmandu (BB Khatri, BP Sharma, PP Khatiwada, KP Paudyal, BR Khadge and HN Regmi, eds) Proc. 4th National Horticultural Research Workshop, 2-4 March 2004, Horticulture Research Division, Nepal Agriculture Research Council, Kathmandu, **pp.** 380-385.

Pariyar D. 2008. Country Pasture/Forage Resource Profiles. FAO. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Nepal.pdf

Pathak H, AN Tewari, S Sankhyan, DS Dubey, U Mina, V Singh, N Jain, and A Bhatia. 2011. Direct-seeded rice: potential, performance and problems. Current Advances in Agricultural Sciences **3**(2): 77-88.

Pathak R, A Kandel, S Dahal and S Mahatara. 2022. Effect of biochar and nitrogen on soil characteristics, growth and yield of radish (Raphanus sativus L.) at Paklihawa, Rupandehi condition of Nepal. Archieves of Agriculture and Environmental Science, **7**(2):150.155. https://doi.org/10.26832/24566632.2022.070202

Pathak P, UC Thakur and D Shrestha. 2011. Climate change and livestock sector: vulnerability and adaptation. Proceedings of the workshop on Climate change: livestock sector vulnerability & adaptation in Nepal; pp. 42-47.

Paudel MN. 2011. Rice (Oryza sativa L.) cultivation in the highest elevation of the world. Agronomy Journal of Nepal **2**:31-41.

Pokharel NP, S Adhikari and S Poudel. 2021. Drought stress effect in wheat genotypes: a review. Food and Agri Economics Review **1**(2):77-79.

Pokhrel A and P Soni. 2018. An investigation into a resource and environmentally sustainable system: zero-tillage lentil and garlic production in Nepal. Agroecology and Sustainable Food Systems **42**(9):982-1002.

Pokhrel A, R Shrestha and SR Dangi. 2021. Screening of soybean genotypes to short period of flood. Agronomy Journal of Nepal **5**:96-103.

Pokhrel KR, TB Ghimire, A Pokhrel and KB BC. 2013. Soybean varietal investigation in river basin area of Mid-Western Nepal. Proc. 27th National Summer Crops Workshop, 18-20 April 2013, Rampur, Chitwan. **pp.**33-35.

Poudel GP, AR Khanal, DB Rahut, TJD Krupnik and AJ McDonald. 2022. Smart precision agriculture but resource constrained farmers: Is service provision a potential solution? Farmer's willingness to pay for laser-land leveling services in Nepal. Smart Agricultural Technology. **DOI:**10.1016/j.atech.2022.100084

Poudel PB, MR Poudel and RR Puri. 2021. Evaluation of heat stress tolerance in spring wheat (*Triticum aestivum* L.) genotypes using stress tolerance indices in western region of Nepal. Journal of Agricuture and Food Research **5**:100179. https://doi.org/10.1016/j/jafr/2021.100179

Prasai HK, SK Sah, AK Gautam and AP Regmi. 2018. Conservation agriculture for productivity and profitability of wheat and lentil in maize based cropping system in far western Nepal. Journal of Bangladesh Agricultural University **16**(3):403-410.

Rani S, Satyvan, A Kumar and S Beniwal. 2019. Integrated nutrient management as a managerial tool for applying saline water in wheat crop cultivated under sub-tropic and semi-arid conditions of North-Western India. Journal of Plant Nutrition. **DOI:** 10. 1080 /01904167 .2019.1685105

RARSP. 2012. Annual Report 2011/12 (2068/69). Regional Agricultural Research Station, NARC, Parwanipur, Bara, Nepal.

RARSP. 2017. Annual Report 2016/17 (2073/74). Regional Agricultural Research Station, NARC, Parwanipur, Bara, Nepal.

RARST. 2015. Annual Report 2014/15 (2071/72). Regional Agricultural Research Station, NARC, Tarahara, Sunsari, Nepal.

Raut N, BK Sitaula, RM Bajracharya and S Karki. 2020. Methane emission from unsustainable crop production in Nepal, system of rice intensification as an option for mitigation. Climate Change and Soil Interactions:37-49. DOI:10.1016/b978-0-12-818032-7.00003-5.

Regmi BR and A Adhikari 2007. 'Climate change and human development-risk and vulnerability in a warming world-country case study Nepal', Occasional Paper, Human Development Report 2007/08. (Taken from MoFE, 2021 TNA report)

Reicosky DC and RR Allmaras. 2003. Advances in tillage research in North American cropping systems. Journal of Crop Production **8**:756-125.

Richards M and BO Sander. 2014. Alternate wetting and drying in irrigated rice. Practice brief. Climate-smart agriculture. Climate Change, Agriculture and Food Security (CCAFS).

Sander BO, R Wassmann, LK Palao and A Nelson. 2017. Climate-based suitability assessment for alternate wetting and drying water management in the Philippines: a novel approach for mapping methane mitigation potential in rice production. Carbon Manage 8:331-342. DOI: 10.1080/17583004.2017.1362945.

Sapkota S, MN Paudel, NS Thakur, MB Nepali and R Neupane. 2010. Effect of climate change on rice production: A case of six VDCs in Jumla District. Nepal Journal of Science and Technology **141**:57-62.

SARPOD. 2012. Annual Report. Socioeconomics & Agricultural Research Policy Division (SARPOD), NARC, Khumaltar, Lalitpur, Nepal.

Shah P, SK Sah, KB Basnet and MN Paudel. 2020. Sesbania knockdown days and seed rates of dry direct seeded rice influence weed dynamics and productivity of rice. Pakistan Journal of Weed Science Research **26**(2):231-242.

SRI-Rice. 2016. SRI methodologies. Available from: http://sri.cals.cornell.edu/aboutsri/methods/index.html

Shahak Y. 2008. Photo-selective netting for improved performance of horticultural crops. A review of ornamental and vegetable studies in Israel. Acta Horticulture **770**:161-168.

Shrestha A, B Thapa, R Subedi, LP Amgain and MW Devkota. 2019. Effect of weed management in productivity of spring maize in Mid-hills of Nepal. Journal of Research in Weed Sciencne **2**:43-51.

Shrestha LL and G Shrestha. 2015. Nutrient management experiment in wheat-common bean system at high hills condition in Nepal. Proc. 2nd national soil fertility research workshop, 24-25 March 2015, Khumaltar, Lalitpur, Nepal.

Shrestha S and KR Dahal. 2015. Assessment of economic viability of different irrigation methods: A case study of Chaar-ghare, Lalitpur, Nepal. IOSR Journal of Mechanical and Civil Engineering **12** (4): 59-65.

Singh M, R Udash, NR Khatiwada and N Pradhan. 2013. Enhancing rural livelihood through rainwater harvesting in Nepal. Geography of Governance: Dynamics for Local Development (PK Pradhan, Jan Bucek and E Razin eds). International geographical union commission on geography of governance.

Singh S, JK Ladha, RK Gupta, L Bhusan, AN Rao, B Sivaprasad and PP Singh. 2007. Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (Oryza sativa L.). Crop Protection **26**:518-524.

Styger E and N Uphoff. 2016. The system of rice intensification (SRI): revisiting agronomy for a changing climate. Global alliance for climate-smart agriculture. SRI-RICE. Practice brief. Climate-smart agriculture.

Suraj PT. 2011. Effect of environmental stress on dairy cattle under different housing pattern in north and western regions in Tamil Nadu. Ph. D dissertation. Tamil Nadu Veterinary and Animal Sciences University; **p** 198.

Teitel M, O Liron, Y Haim and I Seginer. 2008. Flow through inclined and concertina-shape screens. Acta Horticultare **801**:99-106.

Tewolde H, CJ Fernandez and CA Erickson. 2006. Wheat cultivars adapted to post-heading high temperature stress. Journal of Agronomy and Crop Science **192**(2):111-120. https: // doi. Org/10.1111/j.1439-037X.2006.00189.x.

Thakur MK, HK Upreti, R Adhikari and A Arpan. 2017. Watawaran maitri krishi prabidhi sangalo (2073). Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal (in Nepali language).

Thapa CB. 2017. Survey of integrated pest management (IPM) practice in vegetable crops of Rupendehi Districts, Wester Nepal. International Journal of Applied Sciences and Biotechnology **5**(2):237-242.

Thapa K, S Gautam, P Chaudhary, A Khattri-Chhetri, KD Gurung, B Bhattarai, D Rijal, D Gurung, B Paudel and KP Bhatta. 2015. Scaling-Up Climate-Smart Agriculture in Nepal: Inception Report. Local Initiatives for Biodiversity, Research, and Development (LI-BIRD) and CGIAR's Research Program on Climate Change Agriculture and Food Security (CCAFS), Kaski, Nepal.

Thirupathy RV and AP Usha. 2011. Strategies for waste management in pig farms, National symposium on waste management: experiences and strategies. Kerala Agricultural University, Thrissur, Kerala, India.

Timalsina HP, S Marhatta, SK Sah and AK Gautam. 2021. Effect of tillage method, crop residue and nutrient management on growth and yield of wheat in rice-wheat cropping system at Bhairahawa condition. Agronomy Journal of Nepal **5**:52-62.

Timilsina S, A Khanal, SP Vista, TB Poon. 2020. Effect of biochar application in combination with different nutrient sources on cauliflower production at Kaski Nepal. Minist. Agric. Livest. Dev. Singhdurbar, Kathmandu

Timsina KP, YN Ghimire, D Gauchan, S Subedi ad SP Adhikari. 2018. Lessons for promotion of new agricultural technology: a case of Vijay wheat variety in Nepal. Agriculture & Food Security **7**:63. DOI: https://doi.org/10.1186/s40066-018-0215-z

Tiwari DN, SR Tripathi, MP Tripathi, N Khatri and BR Bastola. 2019. Genetic variability and correlation coefficients of major traits in early maturing rice under rainfed lowland environments of Nepal. Advances in Agriculture 2019: 1-9. DOI: https://doi.org/10.1155/2019/5975901

Tripathi BP, J Timsina, SP Vista, YK Gaihre, BR Sapkota. 2022. Improving Soil Health and Soil Security for Food and Nutrition Security in Nepal. **In:** J Timsina, TN Maraseni, D Gauchan, J Adhikari, H Ojha (eds). Agriculture, Natural Resources and Food Security. Sustainable Development Goals Series. Springer, Cham. https://doi.org/10.1007/978-3-031-09555-9_8

Upreti HK, SP Khatiwada, RB Bhujel and JB Adhikari. 2013. Evaluation of cold tolerant rice genotypes for high hill of Nepal. Manandhar et al eds. Proc. 4th SAS-N Convention, 4-6 April, 2012, Lalitpur, Nepal.

Uprety R. 2006. SRI takes root in Nepal. LEISA Magazine **22**:25-27.

USDA-ARS (United States Department of Agricultural Research Services. 2018. A national road map for integrated pest management. https:// www.ars.usda. gov/ARSUserFiles/ OPMP / IPM%20Road%20Map20FINAL.pdf

Van Wijk, L Merbold, J Hammond and K Butterbach-Bahl. 2020. Improving Assessments of the Three Pillars of Climate Smart Agriculture: Current Achievements and Ideas for the Future. Frontiers in Sustainable Food Systems **4**:558483. **DOI:**10.3389/fsufs.2020.558483

VanToai TT, TTC Hoa, NTN Hue, HT Nguyen, JG Shannon and MA Rahman. 2010. Flooding tolerance of soybean [*Glycine max* (L.) Merr.] germplasm from Southeast Asia under field and screen-house environments. The Open Agriculture Journal **4**:38-46. **DOI:** 10. 3389/ fsufs. 202- 0 .558483

Vista SP, YR Thapa and KN Mishra. 2007. Long term application of organic manure and fertilizer on soil chemical properties. Paper presented in: 25th National Summer Crops Workshop 21-23 June 2007 at NARC, Khumaltar.

Wang H, MJ Moore, PS Soltis, CD Bell, SF Brockington, R Alexandre, CC Davis, M Latvis, S Manchester and DE Soltis. 2009. Rosid radiation and the rapid rise of angiosperm-dominated forests. In Proceedings of the National Academy of Sciences 106:3853–8. **DOI**: 10. 1073 / p- n as.0813376106.

Wang Y, R Yin and R Liu. 2014. Characterization of biochar from fast pyrolysis and its effect on chemical properties of the tea garden soil. Journal of Analytical and Applied Pyrolysis **110**: 375–381, https://doi.org/10.1016/ j.jaap.2014.10.006

WB. 2021. Climate risk profile, Nepal. 1818 H Street NW, Washington, DC 20433, USA: World Bank Group. https://openknowledge.worldbank.org/bitstream/handle/10986/8012/FullReport.pdf

WBG. 2022. Country Climate and Development Report. 1818 H Street NW, Washington, DC 20433. https://openknowledge.worldbank.org/bitstream/handle/10986/38012/FullReport.pdf

WBG and ADB. 2021. Climatic risk country profile Nepal. World Bank Group and Asian Development Bank. DOI: https://doi.org/10.1596/36374

WFP. 2021. Nepal Annual Country Report. https://docs.wfp.org/api/documents/WFP-00 0 0 1-37922/download/

World Bank. 2011. Nepal: Priorities for agriculture and rural development. Washington DC: Author.

Woolf D, JE Amonette, FA Street-Perrott, J Lehmann and S Joseph. 2010. Sustainable biochar to mitigate global climate change. Nature Communications **1**(5): 1-9. https://doi.org/10.1038/ncomms1053

www.knowledgebank.irri.org. 2022. Rice knowledge bank. International Rice Research Institute.

Yadav RB, A Kumar and BP Tripathi. 2012. Alternate wetting and drying irrigation system: water saving option for rice cultivation in Nepal. HK Manandhar et al (eds). Proc. 4th SAS-N Convention, 4-6 April 2012, Lalitpur, Nepal.

Ye H, L Song, H Chen, B Valliyodan, P Cheng, L Ali, T Vuong, C Wu, J Orlowski, B Buckley, P Chen, JG Shannon and HT Nguyen. 2018. A major natural genetic variation associated with root system architecture and plasticity improves waterlogging tolerance and yield in soybean. Plant Cell and Environment 41:2169-2182. https://doi.org/10.1111/pce.13190

Yu Q, L Li, Q Luo, D Eamus, S Xu, C Chen, E Wang, J Liu and DC Nielsen. 2014. Year patterns of climate impact on wheat yields. International Journal of Climatology **34**:518-528. DOI:10.1002/joc.3704

Zhang F, Z Cui, X Chen, X Ju, J Shen, Q Chen, X Liu, W Zhang, G Mi, M Fan and R Jiang. 2012. Integrated nutrient management for food security and environmental quality in China. Advances in Agronomy 116:1-40.

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