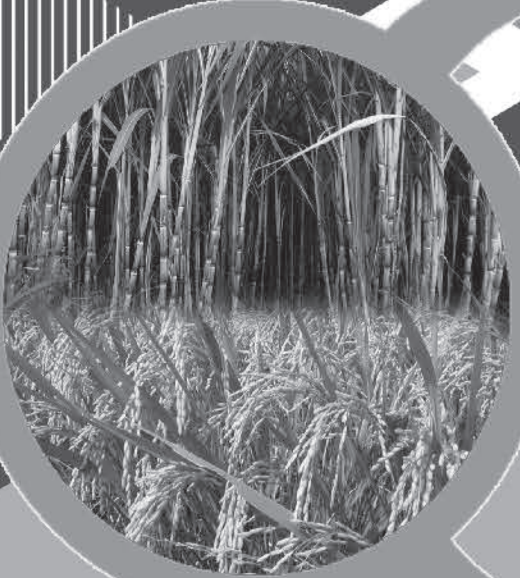
DEPARTMENT OF AGRICULTURE AND FARMERS' WELFARE

UNDER SSEPERS – ATMA -2022-2023

CROP DIVERSIFICATION AND CROP ROTATION FOR OPTIMUM USE OF NATURAL RESOURCES

TRAINING MANUAL



DIRECTOR

STATE AGRICULTURAL MANAGEMENT AND EXTENSION TRAINING INSTITUTE (SAMETI)

KUDUMIYANMALAI.

DEPARTMENT OF AGRICULTURE AND FARMERS' WELFARE

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Foreword

In the present scenario more emphasis is given to cereal-cereal cropping system from Green Revolution period with a motive to feed nation, but under the passage of time, it also led to several challenges such as deterioration of soil health, degradation of land & water resources, depletion of ground water, increase of soil & water pollution due to excessive use of chemical fertilizers and changes in climatic condition. The magnitude of insect-pest and disease problem has also been quantified and many more issues arise due to this mono cropping pattern.

Moreover, continuously growing same crop again and again leads to soil exhaustion and also excessive use of unbalanced dose of N & P results in drain of money. More focus on macronutrient in large quantity has led to multi micronutrient deficiencies. The ***impact of Green Revolution*** has made us self sufficient in cereal-cereal cropping system to increase food grain production. Under this critical situation, the concept of crop diversification strongly came out for the specific cropping system particularly cereal – cereal cropping system. Diversification in the direction of cropping system will help in mitigating many issues or problem related to soil health and soil micro flora and fauna, which are going to be extinct due to large scale use of unbalanced fertilizer.

A refresher course on crop diversification and crop rotation has been arranged at this institute for the ADAs and AOs of Department of Agriculture and Farmers' Welfare. I hope that this training will give impetus to the extension functionaries towards transferring technologies related to crop diversification and rotation.

I extend my best wishes and thanks to TNAU staffs and all the technical staff of SAMETI for the preparation of this technical training manual.

with best wishes

Date:- 31-05-2022

Place:- Kudumiyanmalai

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STRATEGIES AND CONCEPTS FOR CROP DIVERSIFICATION

India, an agriculture-dependent country, has its 60-65% rural population dependent on agriculture for their livelihood. During the green revolution, we moved from being a food-deficient country to being a food-sufficient country. However, associated negative effects of the green revolution on biodiversity and the environment, as well as crop adaptation to climate change, are a growing concern.

Crop diversification also known **as** agricultural diversification refers to the addition of new crops or cropping systems to existing farmland taking into account the different returns on investment. It is shifting from traditionally grown less profitable crops to more profitable crops.

Diversification in agriculture can also be refered to either a change in cropping patterns or the expansion of other non-farming activities like poultry farming, animal husbandry, etc. By doing so, farmers are able to expand their production, thereby generating more income. These changing farming patterns can range from food and nonfood crops, conventional and organic farming, high-value and low-value crops, etc. Diversification of agriculture is possible by growing livestock, fishery, and forestry products in addition to field crops. Crop diversification depends on a region's Geo-climatic conditions, socio-economic development, and technological progress. To meet ever-increasing consumer demand for coarse cereals, pulses, vegetables, fruits, oilseeds, grains, and sugarcane, crop diversification has been designed to shift from the regional dominance of one crop to regional production of multiple crops.

Classification of crop diversification

The Crop diversification in India can be broadly classified into two categories :

Horizontal crop diversification

This kind of crop diversification aligns with farmer's basic understanding of agricultural diversification i.e. not to depend on just one crop. Small farmers with small pieces of land can benefit most from horizontal crop diversification. Instead of cultivating a single crop, this involves multiple crops or a mix of crops. In this way, they are able to earn more through increasing crop diversity.

Vertical crop diversification

Combined with multiple cropping, vertical crop diversification involves the incorporation of industrialization. This kind of agricultural diversification practice is suitable for relatively big farmers with enough finance and land. Instead of just farming multiple crops, farmers also setup facilities for downstream activities such as milling, processing or packaging. This can also include activities like livestock rearing, forestry, polyhouse, horticulture etc.

Reasons for crop diversification

There are various factors of traditional farming, which have triggered the need of crop diversification in India. Plenty of old farming methods and principles which were profitable in the past are now failing to produce desired results. Some of the reason for crop diversification

- Degradation of natural resources such as cultivable land, water scarcity, and soil.
- Climate Change effecting the yield and quality of regional crops
- Decreasing employment in agriculture business.
- Increasing price of food.
- Decreased or plateaued yield of rice based cropping systems.
- Decreased level of organic carbon in soil
- Deficiency of nutrients such as nitrogen, phosphorus, potassium, sulphur, Boron, etc in soil (Noticeably, in rice based cropping systems).
- Decrease in income and purchasing power of farmers.
- Weeds developing resistance to herbicides.
- Increase in insect pest and diseases.
- Inability to exploit new agricultural produce export opportunities.

Type of diversification	Nature of diversification	Potential benefit
Improved structural diversity	Makes crops within field more structurally diverse	Pest suppression
Genetic diversification in monoculture	Cultivation of mixture of varieties of same species in a monoculture	Disease suppression. Increased production stability
Diversify field with fodder grasses	Growing fodder grasses alongside of food/pulse/ oilseed/vegetables	Pest suppression. opportunity to Livestock farming
Crop rotations	Temporal diversity through crop rotations	Disease suppression, Increased production
Polyculture	Spatial and temporal diversity of crops	Insect, pest disease suppression. climate change buffering
Agro-forestry	Growing crops and trees together	Pest suppression and climate change buffering
Mixed landscapes	Development of larger-scale diversified landscapes through mixture of crops and cropping system with multiple ecosystems	Pest suppression, climate change buffering and increased production stability
Micro-watershed based diversification	Integration of crop with other farming components for year round income and employment generation, besides sustaining soil	Insect, pest and disease suppression. climate change buffering and increased production, employment and income

Benefits of crop diversification

Crop diversification has proven to be beneficial not just because it is a modern new farming technique, but also because it manages to overcome a lot of farming problems caused by changing environment, landscape, disease and pest behavior, government policies, supply and demand and trends.

- Greatly reduces farmers risk as the farmer now does not depend on just one crop for income. Unlike the traditional farming methods where failure of the crop resulted in complete exit of that farmer from the market.
- Small farmers are majorly empowered as the total yield of the multiple commercial plants and crop increases.
- Multiple cropping system or multi tier cropping systems greatly increase employment opportunities.
- Increases income of small farms.
- Crop diversification helps in balancing and fulfilling food demand.
- Crop diversification also helps in increasing production of good quality fodder for livestock animals.
- Reduces the ability of pests, insects and weed to become resistant to pesticides and herbicides.
- Agricultural diversification helps in maintaining the quality of natural resources (soil nutrients / soil fertility and water).
- It also helps in minimizing environmental pollution which is caused by excessive use of herbicides and pesticides.
- It opens up new agro business opportunities for budding entrepreneurs (who wish to step into the world of food processing) and also opens up new frontiers for exports of crops, vegetables and fruits.

Challenges in adopting crop diversification

The implementation of crop diversification is facing many issues in its implementation. These issues can be climatic, geographical, financial or human.

- More than 60% of the country's cultivated area is rain-fed and is dependent on rainfall. Hence, areas with less rain have fewer options for crops for crop diversification.
- Suboptimal and excessive use of resources such as land and water, causing negative effects on the environment and sustainability of agriculture.
- An insufficient supply of high-quality seeds and planting materials that are suitable for regional climates.

- In India, in some cases, the landownership can be divided into multiple parties (such as siblings and relatives). The difference of opinion and personal interests also hampers the implementation of crop diversification methodology.
- Sometimes the size of the landholding by a farmer is not enough to achieve agricultural diversification.
- Inability to finance also plays a major part in not being able to adopt this farming methodology.
- Lack of basic infrastructure such as roads, power, transportation, and communications in rural areas.
- The post-harvest handling of perishable horticulture products such as milk, meat, fruits and vegetables, is inadequate due to insufficient technologies and infrastructure.
- The agro-based industry (such as processing units, cold storage, dry storage, government storage, packaging units etc) is weak. Farmers and local markets are not properly connected to the agro-industry.
- The linkage between farmers and research-extension is poor and hence farmers do not have the knowledge of this practice or lack guidance on how to implement it successfully.
- Low farmer illiteracy and insufficiently trained human resources.
- Most crop plants are being affected by new species of diseases and pests.
- There are insufficient investments in the agricultural sector and a poor database of horticultural crops.

Key strategies in crop diversification

- Replacing low yielding and low yielding value crops with high yielding and high yielding value crops that have a longer shelf life.
- Including legume farming in agricultural diversification. Legume farming saves water in the land for the subsequent crop.
- Replacement of high-water-using crops with crops that require less water.
- Including energy efficient crops and plants.
- Planting intercrops in rainfed areas.
- The inclusion of domestically and internationally demanded crops.
- Farming drought-resistant oilseed crops to replace high-risk crops.
- Adopting crop systems that are more productive, profitable and sustainable.

CONSERVATION OF NATURAL RESOURCES THROUGH CROP DIVERSIFICATION

Natural resources are land resources, water resources and forest resources

Land Resources

- More than two thirds of India's population is dependent on land.
- Total land area in India: 304 million ha
- Out of these area roughly 40 million ha are considered unfit for vegetation.
- It is urban, permanent snow, rocks and deserts.

Degraded Lands

- The National Commission on Agriculture estimated that 175 million ha of land was under form of degradation.
- According to the commission, all rainfed paddy lands in the country were subject to water and wind erosion.
- In the 175 million ha the commission included 85 m ha of cultivated land too
- Of the remaining 90 m ha there would be (35 m ha) of degraded and barren forest lands and the rest 55 m ha would constitute **common and revenue lands**

Water Resources

- Other than rivers and canals total water bodies cover all the area of about 7 million hectare
- UTTAR PRADESH occupies first place with total length of rivers and canals as 31.2 thousand kilometers, which is about 17 % of total length of rivers and canals in the country.

Surface Water Resources

- Annual precipitation including snowfall which is the main source of the surface water is estimated to be 4000 cubic km.
- Resource potential of the country which occurs as natural runoff in the rivers is about 1869 cu.km.
- Ganga- Brahmaputra Meghna system is the major contributor to total water resource potential of the country.
- Its share is about 60% of total water resource potential of country.

- Due to various constraints of topography, uneven distribution of resources over space and time, it has been estimated that only 1122 cubic km of total 1869 cubic km is under beneficial use.
- Of this 690 cu. Km is due to surface water resources.
- In majority of river basins present utilisation is significantly high and in the range of 50%to 95% of utilisable surface resources.

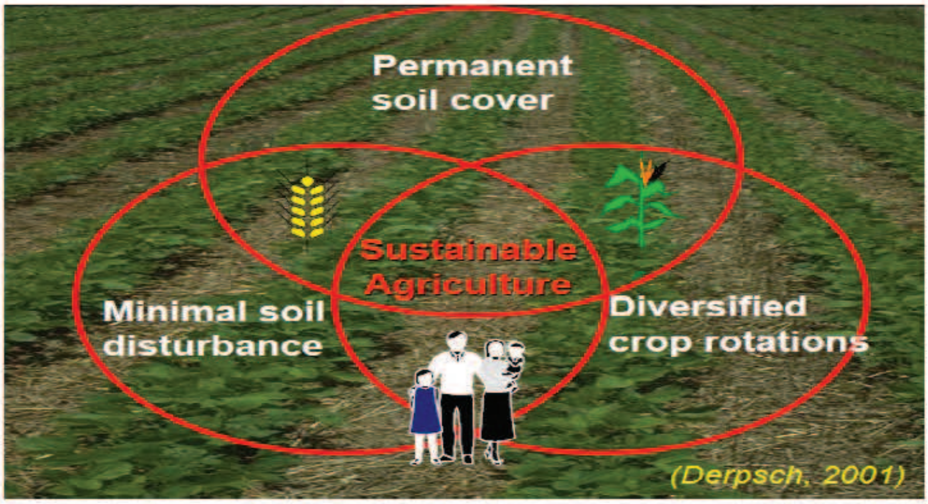
What is conservation agriculture?

Conservation agriculture (CA) is described by FAO (http: // www.fao.org/ag/aca) as a concept for resource saving agricultural crop production which is based on enhancing natural and biological process above and below ground.

As per FAO definition CA is to i) achieve acceptable profits ii) high and sustained production levels, and iii) conserve the environment

CA goals defined by FAO as follows

1. CA aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs.
2. It can also be referred to as resource efficient or resource effective agriculture



Benefits of Conservation Agriculture

AGRONOMIC BENEFITS

- ❖ Improvement of soil productivity
- ❖ Increased Organic matter content
- ❖ Soil water conservation
- ❖ Improvement of soil structure

Environmental Benefits

- reduction in soil erosion
- improvement of water quality
- improvement of air quality
- Better biodiversity
- Carbon sequestration

Economic Benefits

- Time saving and less labor requirement
- Higher efficiency
- Reduction of costs

Conventional Agriculture over the years leads to soil threats

- Soil erosion/ desertification
- Soil organic matter reduction
- Soil contamination
- Soil compaction
- Extra CO_2 emission into atmosphere
- Lesser storage of water in the soil profile
- Decline in soil biodiversity
- Salinization
- Floods and land slides

How conservation agriculture address these problems

1. It is significantly different approach to land husbandry because it involves adoption of biological tillage principles
2. CA starts from the principle that soil disturbance through mechanical tillage is detrimental
3. Conservation tillage practices were developed to target in particular the issue of erosion through reducing tillage effort and leaving 30% soil cover by mulching with crop residue
4. It involves change of practice on part of the farmer, but adoption of CA requires a more radical shift in thinking- a new paradigm

Different practices of conservation agriculture

1. Managing Topography

1. Contour farming 2.Terracing 3.Strip farming 4. Waterways

2. Conservation tillage

It is any tillage and planting system that maintains at least 30% of the soil surface covered by residues after planting to reduce water erosion or where wind erosion is the primary concern maintain at least 1000 kg/ha of small grain residues equivalent on the surface during the critical wind erosion period.

Types of conservation tillage

No tillage or Zero tillage

Here soil is completely left undisturbed from harvest to planting except sowing nutrient application. Weed control is only by herbicide.

Reduced or Minimal tillage

Little soil disturbance before sowing to break the crust, loosen compact soil and prepare seedbed. Weed control by herbicides **or some secondary tillage.**

Mulch tillage

Tillage is practiced only to sow the crop, equipments don't bury the crop residues. Weed control by herbicides or some secondary tillage.

A comparison of Traditional tillage (TT) conservation tillage (CT) and conservation agriculture for various issues

Issues	Traditional tillage (TT)	Conservation tillage (CT)	Conservation agriculture (CA)
Practice	Disturbs the soil and leaves a bare surface	Reduces the soil disturbance in TT and keeps the soil covered	Minimum soil disturbance and soil surface permanently covered
Erosion	Wind and soil erosion: maximum	Reduced significantly	The least of the three
Soil physical health	The lowest of the three	Significantly improved	The best practice of the three
Compaction	Used to reduce compaction and can also induce it by destroying biological pores	Reduced tillage is used to reduce compaction	Compaction can be a problem but use of mulch and promotion of biological tillage helps reduce this problem
Soil biological health	The lowest of the three owing to frequent disturbance	Moderately better soil biological health	More diverse and healthy biological properties and populations
Water infiltration	Lowest after soil pores clogged	Good water infiltration	Best water infiltration
Soil organic matter	Oxidizes soil organic matter and causes its loss	Soil organic build-up possible in the surface layers	Soil organic build-up in the surface layers even better than CT

Weeds	Control weeds and also causes more weed seed to germinate	RT control weeds and also exposes other weed seeds for germination	Weeds are problem especially in the early stage of adoption
Soil temperature	Surface soil temperature More variable	Intermediate in variability	Moderated the most
Diesel use and cost	Diesel use: High	Intermediate	Much reduced
Production costs	Highest	Intermediate	lowest
Yield	Can be lower where planting delayed	Yields same as TT	Yields same as TT but can be but can be higher if planting done more timely

3. Providing Soil Cover

A. Mulching

- Prevent splash erosion by heavy rains and surface runoff
- Improves soil texture by adding organic matter

B. Cover crops

- Recycling nutrients and water
- Enhance microbial activity

C. Crop Rotation

- Increased farm incomes by reducing cost of production and climatic risks.
- The rotation of crops offers a diverse "diet" to the soil micro organisms.

Constraints for adoption of CA

- ❖ Lack of appropriate seeders especially for small and medium scale farmers
- ❖ The wide spread use of crop residues for livestock feed and as fuel
- ❖ Burning of crop residues
- ❖ Lack of knowledge about the potential of CA among leaders, extension agents and farmers

SOIL BIODIVERSITY, CROP ROTATION AND CROP DIVERSIFICATION ARE VITAL COMPONENTS OF HEALTHY SOIL AND AGRICULTURAL SUSTAINABILITY

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Soil biodiversity

Soil biodiversity reflects the variability among living organisms including a myriad of organisms not visible with the naked eye, such as micro-organisms (e.g. bacteria, fungi, protozoa and nematodes) and mesofauna (e.g. acari and spring tails), as well as the more familiar macro-fauna (e.g. earthworms and termites). Plant roots can also be considered as soil organisms in view of their symbiotic relationships and interactions with other soil components.

These diverse organisms interact with one another and with the various plants and animals in the ecosystem forming a complex web of biological activity. Soil organisms contribute a wide range of essential services to the sustainable function of all ecosystems. They act as the primary driving agents of nutrient cycling, regulating the dynamics of soil organic matter, soil carbon sequestration and greenhouse gas emission, modifying soil physical structure and water regimes, enhancing the amount and efficiency of nutrient acquisition by the vegetation and enhancing plant health. These services are not only essential to the functioning of natural ecosystems but constitute an important resource for the sustainable management of agricultural systems.

Biological diversity or 'biodiversity' is described as "the variability among living organisms from all sources whether terrestrial, aquatic or marine". It includes the diversity within species (Genetic Diversity), between species (Organism Diversity) and of ecosystems (Ecological Diversity). Soil is one of the most diverse habitats on earth and contains thousands of different organisms, which interact and contribute to the global cycles that make all life possible.

Facts about soil biodiversity

In nature species are so densely packed as in soil communities. Soil biodiversity is characterized by: Over 1000 species of invertebrates may be found in a single m^2 of forest soils. Many of the world’s terrestrial insect species are soil dwellers for at least some stage of their life-cycle.

A single gram of soil may contain millions of individuals and several thousand species of bacteria. A typical, healthy soil might contain several species of vertebrate animals, several species of earthworms, 20-30 species of mites, 50-100 species of insects, tens of species of nematodes, hundreds of species of fungi and perhaps thousands of species of bacteria and actinomycetes. Soil contains the organism with the largest area. A single colony of the honey fungus, *Armillaria ostoyae*, covers about 9 km^2.

Soil Biodiversity, Soil Conservation and Agriculture

Our agricultural activities exert an important influence on the soil biota, their activities and diversity. Clearing forested or grassland for cultivation drastically affects the soil environment and hence reduces the number and species of soil organisms. The reduction of quantity and quality of plant residues and the number of higher plants species leads to a reduction in the range of habitats and foods for soil organisms.

Different types of agricultural practices and systems affect the soil biota in different ways and the response may be either positive or negative depending on which part of the soil the biota, e.g. fungal or bacterial, is affected. For example, organisms which are sensitive to pH will be affected by the addition of lime; the bacterial: fungal ratio will be affected by the addition of fertilizers and manures which alter the C:N ratio as well the effects of tillage. Tilling the soil will reduce the number of fungal hyphe, because soil aggregates, which are held together by these hyphe are broken down

About 99% of the world's food supply comes ultimately from land-based production with about 50-70% of the land devoted to agriculture. As the population is estimated to reach 9-10.5 billion by 2050 we cannot ignore the health of the 'soil organism' if we want to be able to provide food and feed for increasing consumption and sustain our soil resources. Modern agricultural methods such as plowing, fertilizer application and pesticides have often replaced biological soil functions and increased the reliance on external inputs to maintain productivity, which in the long run is unsustainable.

Research in Soil Biodiversity

The research on soil biodiversity and its link with ecosystems has concentrated on investigating the role of a few taxonomic groups and indicator organisms. In many cases, the research has been hampered by the lack of suitable tools, particularly with microbial species. Many of the early techniques applied to soil microorganisms were originally developed for working with pure cultures of microorganisms. However, the complex soil environment exhibits a significant problem for studying the effects of microorganisms (Rillig, 2004). For example, it is thought that soil contains many species which cannot be cultured by conventional means. Furthermore, given the heterogeneity of soil, information obtained from pure cultures may not be readily translated to the soil environment.

However the increasing use of new molecular tools, looking at genes in the environment and using stable isotopes (^{13}C and ^{15}N) help solving many of the problems associated with research on soil biodiversity.

Some recommendations for research on soil biodiversity can be made:

- Better understanding of the taxonomy of soil organisms.
- Better understanding of the function of soil organisms in the context of nutrient webs.
- Application of ecological theory to soil (microbial) ecosystems.
- Role of soil organisms in high input agro ecosystems
- Use of soil biodiversity for bio-prospecting.
- Linking ecosystem scales: small to large.
- Environmental and temporal gradients.
- Sequencing of soil meta genome.
- Putting a value on soil biodiversity

Soil biodiversity provides both direct (the organisms themselves and/or their metabolic products) and indirect (the long-term outcome of their activities) services to mankind. Therefore, the term 'ecosystem service' was coined (Gómez-Baggethun et al. 2010), so as to be able to put an economic value on biodiversity in general and soil biodiversity in particular. Selected organisms from different functional groups (i.e.micro symbionts, decomposers, elemental transformers, soil ecosystem engineers, soil-borne pest and diseases, and micro regulators) are used to illustrate the linkages of soil biota and ecosystem services essential to life on earth as well as with those associated with the provision of goods and the regulation of ecosystem processes. These services are not only essential to ecosystem function but also a critical resource for the sustainable management of agricultural ecosystems.

Species diversity of soil organisms maintains the functions and resilience of soil. Any perturbation may affect soil activity and any deleterious outside effects can be reduced if the functions of the soil are spread amongst different species. Removal of one keystone species or ecosystem engineer, may lead to catastrophic effects on the ecosystem. Similarly, the introduction of a keystone organism may also have catastrophic or beneficial effects, depending on the situation. This can be considered to be 'ecological health' and results from the many components which make up functions such as nutrient cycling or energy transfers. Soil biodiversity and soil health can also be seen as one measure of environmental quality, because the functioning of the soil system may be the key to understanding the health of agro ecosystems.

The problems in conserving soil biodiversity

Many of the problems in conserving biodiversity are associated with the lack of recognition of the importance it plays in agricultural production. Although many famers and the farming community have a profound knowledge of their agriculture, training and education is often needed to highlight the roles of the soil biota at various levels of the ecosystem/landscape. Soil quality assessments such as chemical and physical properties provide some knowledge of resources but should be supplemented with information on resources (human and organic such as composts) and biological indicators of soil quality and function.

To overcome any limitations to agricultural production, proposed a series of potential 'entry points' at which management practices could be improved. These include both direct interventions such as: inoculation for disease and pest control and soil fertility improvement (such as rhizobia, actinomycetes, mycorrhizae, diazotrophs) and indirect interventions through, for example, cropping system design, organic matter management and genetic control of soil function (manipulating resistance to disease, organic matter and root exudates). A potential set of improvements could be tested together using an “adaptive” experimentation approach whose results feedback over a number of cropping cycles. This would involve other members of the farming community such as extension agents and local community facilitators and be evaluated according to local agricultural, climatic, soil, socio-economic and cultural conditions as long as the farmers etc can identify problems that may lead to the failure of the adopted system. Any system undertaken must be flexible to meet the needs and priorities of those concerned.

The final decision of whether to adopt the practice is by no means certain as the farmer may choose to revert back to the traditional management strategy. The selection of best practice is a long term process and requires a level of commitment, for example monitoring, and the appropriate incentives so that the improvements in agricultural production and human wellbeing can be shown and sustained.

Crop Rotation

Crop rotation is defined as the intentional planting of different types of crops in different parts of the field and at different seasons in a sequential manner. It also entails not choosing to plant anything at all in a given season and allow the land to rejuvenate while bare until the next season. In crop rotation, one can also incorporate livestock in the practice when the land is left bare for a season of grazing. In the very early years, farmers used to practice crop rotation, but they had no idea of the scientific reasons behind the success of the practice, nor did they have the specific term for the practice. This means they did not even know its impact on the environment. Typically, they did it because of the seasonal calendar of the planting of crops, which was set traditionally as a planting pattern. Here are some of the known advantages and disadvantages of crop rotation.

Advantages of Crop Rotation

Increases Soil Fertility

Prolonged planting of the same crop type leads to the depletion of specific nutrients in the soil. Each crop type has a different nutrient interaction with the soil and each of them releases and absorbs different types of nutrients. Because of this, crop rotation increases soil fertility by controlling deficient or excess nutrients because it replenishes nutrients that are not available or absorb nutrients that are in abundance. It also increases and improves the soil organic matter caused by the microorganisms left behind by each type of crop planted. Animals that also graze on land left to fallow contribute to adding manure to the ground that fertilizes the soil. Biomass left behind when harvesting also improves the fertility of the soil as it is purely green manure.

Increases Crop Yield

Crop rotation increases the harvest obtained from a single seasonal harvest. Some scientific evidence proves a 10 to 25% increase in crop yield in crop rotation rather than monoculture. The availability of nutrients from the soil provides abundant nourishment to all plants, therefore, ensuring success in the yield produced.

Increases Soil Nutrients

Crop rotation allows the land to regenerate and rejuvenate its self-nutrients without having to apply more nutrients through the use of fertilizers. Leaving the land bare for a season enables the land to restore the soil nutrients lost through absorption by plants harvested in the previous season. By planting crops like legumes, for example, one can increase nitrogen in the soil as they contain nitrogen-fixing bacteria that fix nitrogen naturally into the soil. Each crop type adds up or absorbs different soil nutrients to the soil; therefore, it needs a mix up of a variety of plants to make them more balanced. Knowing the type of plants to grow after a rotation is imperative to avoid either excessive build-up of nutrients or excessive absorption of nutrients from the soil.

Reduces Soil Erosion

Soil erosion is the carrying away of the most important topsoil layer by wind or water. When the soil is constantly covered by plants, the topsoil layer is not carried away by water during heavy rainfall. Crop rotation also helps reduce raindrop impact on the soil and general erosion by water because the roots of the plants hold the top layer soil together. Trees planted together with crops in the farms also assists in preventing soil erosion.

Limits the Concentration of Pests and Diseases

Similar plants tend to have the same pathogens; therefore, crop rotation intercepts the pest life cycle and their habitat. Farmers can see a decrease in the incidence of insect pests and pathogens when they try crop rotation. Crop rotation lowers the risk of plants getting infested and equally allows the farmer to grow crops each season without using pesticides, which is good for the environment.

Reduces the Stress of Weeds

Crop rotation is a traditional weed control technique that also helps in the weed free cultivation of crops. Crop rotation allows the crops to crowd out weeds during competition of nutrients and other resources. Crop rotation thus reduces the population of weed or better yet, denies them an opportunity to grow.

Improves the Soil Structure

Crop rotation helps prevent soil compaction, thus improving the physical condition of the soil. Crop rotation improves the soil structure as well as soil texture. This allows for good conditions for seed germination and root proliferation. It also helps with other soil processes such as water infiltration and aeration, which have a lot of benefits to the crops and improves the composition of the soil. However, it all depends on the type of crops being rotated, such as cover crops that reduce the spread of weeds, thereby reducing tillage that damages the soil structure. An important element in the soil structure is the pores. With large pores in the soil, water easily drains while small pores in the soil do not allow for proper air and water circulation. Crop rotation generally helps to improve the soil structure.

Reduces Pollution

The constant application of fertilizers to soils causes soil leaching, which is the excessive build-up of nutrients in the soil to a toxic and harmful level that does not allow plants to grow well. Crop rotation increases the nutrients in the soil, and it prevents the accumulation of toxic chemicals or substances secreted by some crop plants. Crop rotation also reduces the constant infestation of crops by pests and diseases, stopping the need for spraying the crops with pesticides. Although pesticides work very well on crops, they contain dangerous chemicals that can build up in the soil to harmful levels. The chemicals may also find their way in waterways when the rainwater washes them off from the farms, and the build-up results in the rise in levels of toxicity in the water.

Diversification and Reduced Cost of Production

The cultivation of certain crops requires less labor and machinery compared to others. It helps to distribute the workload and resources used throughout the year for which the cost of production of the crops decreases to a certain extent. This mostly depends on the crop we select. Besides, the farmers get more options in selling various products and are not reliant only on one crop and market price.

The Nutrient Uptake Regulation

Crop rotation helps in increasing the nutrient uptake of the plants from the soil as in crop rotation, different crops require different nutrients in different quantities.

Disadvantages of Crop Rotation

It Involves Risk

In crop rotation, investing in a season involves the input of much money to buy different seedlings of the different types of crops to be planted. Moreover, certain crops need specific kinds of equipment, so farmers may have to invest in different types of machinery. This means the initial costs can be higher. The success, however, for each crop type is not guaranteed and one can end up incurring a loss of harvest. In addition, pests and diseases from other crops can spread and infect more crops. There is also the risk of a certain crop yield not being successful, and that was the only crop type grown, meaning there will be no yields for that planting season, and the farmer will have to wait for the next season.

Improper Implementation Can Cause Much More Harm than Good

Improper implementation of this technique causes much more harm than good. If one lacks the technical knowhow of crop rotation, there is no need to experiment because there can be nutrient build-up that will take a longer time to correct. One has to have the skills to know what crops can be planted after the other and in which season for the process to be successful.

Improper implementation, hence, makes the farmer incur very great losses. Still, information about the different planting techniques are easily available, and the farmer should be vigilant as well as ready to practice them as required.

Obligatory Crop Diversification

For crop rotation to work, one has to plant different crops every time. The farmer is not able to produce a single crop on a large scale over a long period of time because of the damage it will do to the soil. The practice of crop rotation is necessary to improve yields. Crop diversification also requires investment in different planting techniques for each unique crop that costs time and money because each crop needs a different type of attention.

Requires More Knowledge and Skills

Crop rotation means a variety of crops; therefore, it requires a deeper set of skills and knowledge regarding each type of crop harvested. It also requires different types of machinery, and operating them also requires knowledge. This means farmers will have to invest more time and resources in learning and mastering this agricultural practice.

The Difference in Growing conditions

Certain locations and their climates are more favourable for monoculture, meaning a certain kind of crop. Other than that particular kind of crop, other crops cannot grow well in that specific type of temperature and soil conditions.

RESILIENCE IN AGRICULTURE THROUGH CROP DIVERSIFICATION

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Managed eco systems often fail to respond smoothly to external changes and pressures hassled to greater research on ecological regime shifts, thresholds and resilience. Although the idea of building resilience has been studied in a broad range of ecosystems, from coral reefs to forests, this idea has not been well studied in an especially important system to human society and the agro ecosystem. The development of resilient agricultural systems is an essential topic because many communities greatly depend on the provisioning ecosystem services of such systems (food, fodder, fuel) for their livelihoods. Many agriculture-based economies have few other livelihood strategies and small family farms have little capital to invest in expensive adaptation strategies, which increases the vulnerability of rural, agricultural communities to a changing environment. The challenge for the research community is to develop resilient agricultural systems using rational, affordable strategies such that ecosystem functions and services can be maintained and livelihoods can be protected.

Environmental changes may affect many different aspects of agricultural production. With greater climate variability, shifting temperature and precipitation patterns, and other global change components, we expect to see a range of crop and ecosystem responses that will affect integral agricultural processes. Such effects include changes in nutrient cycling, soil moisture, as well as shifts in pest occurrences and plant diseases, all of which will greatly influence food production and food security. These changes are expected to increase a biotic and biotic stress, forcing agricultural systems to function under greater levels of perturbation in the future.

Resilience is defined as the propensity of a system to retain its organizational structure and productivity following a perturbation. Thus, a resilient agro ecosystem will continue to provide a vital service such as food production if challenged by severe drought or by a large reduction in rainfall. In agricultural systems, crop biodiversity may provide the link between stress and resilience because adversity of organisms is required for ecosystems to function and provide services. Removing whole functional groups of species or removing entire tropic levels can cause eco systems to shift from desired to less-desired state, affecting their capacity to generate ecosystem services. This effect highlights the possibility that agricultural systems already may be in a less-desired state for the continued delivery of ecosystem services. Role of diversity in agro eco systems to functional capacity and resilience: First, biodiversity enhances ecosystem function because different species or genotypes perform slightly different roles and therefore occupy different niches. Second, biodiversity is neutral or negative in that there are many more species than there are functions; thus, redundancy is built into the system. Third, biodiversity enhances ecosystem function because those components that appear redundant at one point in time may become important when some environmental change occurs. The key here is that when environmental change occurs, the redundancies of the system allow for continued ecosystem functioning and provisioning of services. These three hypotheses are not mutually exclusive and change overtime and space; therefore, all linkages between diversity and function may be useful for the long-term maintenance of sustainable agricultural systems. Biodiversity which allows for the coexistence of multiple species, fulfilling similar functions, but with different responses to human landscape modification enhances the resilience of ecosystems. This concept is linked to the insurance hypothesis, which proposes that biodiversity provides an insurance or a buffer, against environmental fluctuations because different species respond differently to change, leading to more predictable aggregate community or ecosystem properties. Such diversity insures the maintenance of a system's functional capacity against potential human management failure that may result from an incomplete understanding of the effects of environmental change.

Advantages of diversified agro ecosystems

Current knowledge suggests that climate change will affect both biotic (pest, pathogens) and abiotic (solar radiation, water, temperature) factors in crop systems, threatening crop sustainability and production. More diverse agro ecosystems with a broader range of traits and functions will be better and able to perform under changing environmental conditions which is important for the expected changes to biotic and abiotic conditions. The following are a few of the major ways that the greater functional capacity of diverse agro ecosystems has been found to protect crop productivity against environmental change.

Pest suppression

Pest suppression is a perennial challenge to farmers, and it is a very important ecosystem service. In agricultural systems, as in natural ecosystems, herbivorous insects can have significant impacts on plant productivity. The challenges of pest suppression may intensify in the future as changes in climate affect pest ranges and potentially bring new pests into agricultural systems. It is expected that insect pests will generally become more abundant as temperatures rise as a result of range extensions and phenological changes. This abundance will be accompanied by higher rates of population development, growth, migration, and over wintering. Changes in the distribution and abundance of species and communities are unlikely to occur at the same rates. Migrant pests are expected to respond more quickly to climate change than plants, and they may be able to colonize newly available crops and habitats. However, there are a variety of barriers to range expansions, including such biotic factors as competition, predation, and parasitism from other species. Promoting such barriers to range expansion and pest viability will have an immediate negative impact on pest out breaks and will help protect agricultural production. Farmers may be able to assist in creating biotic barriers against new pests by increasing the plant diversity of their farms in ways that promote natural enemy abundance. The composition of the plant community, as determined by a farmer, may be described as the planned diversity of the system. Crop diversity is critical not only in terms of production but also because it is an important determinant of the total biodiversity in the system. With greater plant species richness and diversity in spatial and temporal distribution of crops, diversified agro ecosystems mimic more natural systems and are therefore able to maintain a greater diversity of animal species, many of which are natural enemies of crop pests.

Examples of diversification in agricultural systems and the potential benefits for farmers under climate change.

Type of diversification	Nature of diversification	Benefit	Examples
Increased structural diversity	Makes crops within in the field more structurally diverse	Pest suppression	Strip cutting alfalfa harvest allows natural enemies to migrate from harvested strips to adjacent non harvested ones
Genetic diversity in monoculture	Growing mixed varieties of species in monoculture	Disease suppression	Genetic diversity of rice varieties reduces fungal blast occurrence
		Increased production stability	Increased genetic diversity was positively related to mean income and stability of income
Diversify field with non crop vegetation	Growing weeds strips or vegetation banks in and alongside crops	Pest suppression	Grass land or refugia planted at field margins were used as over wintering habitat for natural enemies. Using white and black mustard on the field margins of sweet corn crop trapped pests and prevented them from entering the corn field.
Crop rotations	Temporal diversity through crop rotation	Poly cultures	Growing two or more crop species and wild varieties within the field; spatial and temporal diversity of crops

		Disease suppression	Alternating cereal crops with broad leaf crop and changing stand densities disrupts the disease cycles. Grass land fields planted with multiple species to decrease the disease transmission.
		Increased production	Manipulating diversity through crop rotations over crop and nitrogen fixing crops increased the yield of the primary crop
		climate change buffering	More ecologically complex systems with wild varieties and temporal and spatial diversity of crops were able to grow under climate stress.
		Increased production	Grassland plots with greater field species diversity into more stable feed and fodder production
Agro forestry	Growing crops and trees together; spatial and temporal diversity	Pest suppression	Greater shaded diversity increased bird natural enemy abundance for larval control on crop plant.
		Climate change buffering	Greater shade cover led to increased buffering of crops to temperature and precipitation variation
Mixed landscape	Development of large scale diversified landscapes with multiple eco systems	Pest suppression	Complex landscapes that have areas of woodland and hedge rows interspaced within field shade higher rates of larval parasitism.
		Increased production	Mixed land use of organic crop land, crop rotations, and intensive managed grazing led to optimal diversity and profitability strategies.

Habitat management is one method used within agricultural systems to alter habitats to improve the availability of the resources natural enemies required for optimal performance. Such management techniques have been developed for use at within crop, within farm, or landscape scales, and some have been proven to be very economical for farmers. In an overview examining pest management in agriculture, the authors found that many degrees of complexity exist in increasing biodiversity for pest management. Simply diversifying the plantage structure of a monoculture or strip cutting fields such that natural enemies have a temporal refuge can improve infield habitats for natural enemies. Larger-scale changes, such as integrating annual and perennial non crop vegetation increasing crop diversity within the field or increasing farm wide diversification with sylviculture, agro forestry and livestock may also provide a variety of other functions to the system.

One example of a perennial system that exhibits a rich range of natural enemy pest control is the coffee agro forestry system, where there is a wide variety of spatial and temporal diversity determined by the shade trees planted within the cropping system. Greater natural enemy presence has been observed in the more diverse and shaded agro forestry systems, and increased bird diversity and density have been shown to reduce herbivore plant damage through greater insectivorous bird predation. It has also been observed that predatory ground dwelling ants are attracted to and prey upon the coffee berry borer, a major pest of coffee production, with greater efficiency in diversified coffee systems when compared with un shaded monocultures. The integration of diversified systems into agriculture can have financial benefits for the farmer, as well. One financially beneficial type of habitat management that has been widely adopted at the within-field scale is the beetle bank, where native grasslands and refugia are maintained at the field margins to protect carabid (ground) beetle populations.

Disease suppression

Losses caused by pathogens can contribute significantly to declines in crop production, and changes in climate potentially could affect plant disease distribution and viability in new agricultural regions. The diversity of crop species in an agro ecosystem has a much less predictable effect on microbial pathogens compared with crop pests, as microclimatic conditions play an important role in the development and severity of a disease. The effect of climate change on disease prevalence is therefore much less certain. Climate change could have positive, negative, or no impact on individual plant diseases, but it is suspected that milder winters may favor many crop diseases, such as powdery mildew, brown leaf rust, and strip rust, whereas warmer summers may provide optimal conditions for other diseases, such as cercospora lead spot disease. Global change is also predicted to alter the distribution and abundance of arthropod vectors that distribute viruses, thereby affecting the rates of and chances for crop transmission.

The loss of genetic diversity in crop production has led to a hypothesized increase in crop diseases susceptibility as a result of higher rates of disease transmission. Many mechanisms reduce the spread of disease in agricultural systems with greater varietal and species richness. Barrier and frequency effects occur when other disease resistant varieties or species block the ability of a disease or virus to transmit and infect a susceptible host. These effects increase with greater spatial and temporal diversity in the agricultural system, and intentional crop system diversity with greater barrier effects can significantly reduce pathogen impacts on crop production.

These examples show that farmers can take advantage of greater crop diversification to reduce disease susceptibility in agricultural systems, thereby limiting the amount of production loss as a result of crop diseases. Although changes in disease spread and severity are uncertain under climate change, greater genetic variation across space and time could potentially reduce adverse disease transmission impacts that may accompany climate change.

Climate variability buffering and mitigation

Diversified agro ecosystems have become more important for agriculture as climate fluctuations have increased. Research has shown that crop yields are quite sensitive to changes in temperature and precipitation, especially during flower and fruit development stages. Temperature maximums and minimums, as well as seasonal shifts, can have large effects on crop growth and production. Greater variability of precipitation, including flooding, drought, and more extreme rainfall events, has affected food security in many parts of the world.

Agro forestry systems are examples of agricultural systems with high structural complexity. Although the primary crop of interest (e.g., coffee, cacao) is sometimes grown in more intensively managed systems with little shade cover, the more structurally complex systems have been shown to buffer crops from large fluctuations in temperature, thereby keeping crops in closer-to-optimal conditions. The more shaded systems have also been shown to protect crops from lower precipitation and reduced soil water availability because the over story tree cover reduces soil evaporation and improves soil water infiltration.

Diversification of agricultural systems can significantly reduce the vulnerability of production systems to greater climate variability and extreme events, thus protecting rural farmers and agricultural production.

Incentives favor greater production of fewer species planted in space and time, at the expense of ecosystem services and ecosystem function. Incentives for the greater production of fewer crops have also been supported by the mechanization of many agricultural production practices (e.g., planting, harvesting). Mechanization is now the status quo in the United States and is necessary for this type of production system. The mechanization of crop species for maximum production, in general, is most efficient when only one crop is planted because management systems (e.g., planters, harvesters, chemical inputs, irrigation systems) can be designed for one crop type and one crop structure, thereby decreasing labor time and costs. In this sense, an agricultural system that selects mainly for one or two main crops and is highly mechanized can be very efficient and productive, and certainly this ability to scale up production and increase yield has had many advantages for food production and the maintenance of stable food prices in the past.

Incentives that can increase economic productivity of farms by permitting the selling of ecosystem services, such as carbon sequestration, have the potential to increase the adoption of diversified farm systems such as terraces and agro forestry. Developing policy that incentivizes the diversification of agricultural crops and landscapes may be a more rational strategy for developing resilient agricultural systems and protecting food production in the future under climate change.

Biotech solutions

The recognition that agriculture will face challenges under climate change has brought about a major effort to adapt agriculture through technical means, primarily the research and development of drought resistant biotech crops. The push for greater use of biotechnology that focuses on sole crop agriculture has made some head way in protecting production yields for some farmers, but it has not succeeded in many situations, especially in developing nations. Such products may also be prohibitively expensive, which will pose a challenge for small holder rural farmers who may want to pursue this adaptation option under climate change.

If there is indeed a temporal scale mismatch in the rate of development of adequate bio tech lines and the rate and extent of climate change effects on agriculture, farmers will have to turn to other adaptation options to improve their silence of their systems to climate change. The need to develop options for present and expected climate change and for those who will have no access to such technology remains a great problem for agricultural development and food security fields. Diversified agriculture in such cases remains a highly accessible adaptation option for many farmers.

Biomass production

The belief that monocultures and intensively managed systems are more productive than diversified agricultural systems is another challenge to moving agricultural systems toward more diversity. Maximizing biomass production of one or two specific crops is essentially the goal of the current modern agricultural paradigm. Although ecosystem functioning of such systems persists at much reduced capacity, outside infrastructure such as mechanization, chemical inputs, and irrigation systems can help to replace the lost functionality to enable high production. However, the potential effects of climate change on agriculture stability will further complicate our predictions of production and pricing of goods from large scale, mono cropped systems. In many regions of the World, the ability to use intensified production practices and products is limited by cost and transportation. Petroleum for mechanization techniques and chemical inputs can be prohibitively expensive. Even in regions with access to mechanization and chemical inputs, a lack of water resources can severely reduce production capacity. In such cases, diversified agricultural systems that are able to produce under extreme climate scenarios are preferable because many of the ecosystem functions that cannot be brought into the system through inputs and mechanizations can be provided through natural means. Such solutions support both biodiversity and community resilience to climate change by taking advantage of ecosystem functions and services, supporting high production yields in potentially adverse environmental conditions.

Developing optimization strategies and win-win solutions for diversification

A major challenge for the implementation of diversified agricultural systems for farmers is finding the appropriate balance of diversification within the farm system to satisfy both production and protection values. Farmers and agricultural managers must consider the variety of ways that diversification can occur within the system and develop methods that best meet their specific needs of crop production and resilience. Of course, as climate change variability increases, the value of resilience will also increase, especially in production systems sensitive to climate variation. However, a farmer's decision to move towards diversified agricultural systems will be highly influenced by the ability of the diversification strategy to support the economic resilience of farms. Cost-cutting examples, such as the use of beetle banks to reduce pesticide costs or the reduction of fungicide use in integrated rice systems, illustrate the significant possible economic benefits of greater biodiversity. Policy incentives that strongly promote adaptation are also necessary for transitioning agriculture to a long-term sustainable state. Finding win-win solutions that account for farmers' various production and protection goals is necessary to develop long term, viable strategies.

Optimizing diversification strategies at various scales

Developing tools that can help managers to understand best practices on a farm field or landscape scale can significantly enhance diversity in agricultural systems while increasing the resilience of systems to climate change and maintaining high yields.

At the farm field level, techniques such as crop modeling (e.g., Decision Support System for Agro technology Transfer, Agricultural Production Systems Simulator) allow researchers to simulate crop mixtures within a specific regional setting in order to model crop thresholds and production levels to climate and management variables. Such systems can be very powerful for modeling crop outcomes under climate change scenarios, as climate data can be adjusted to mimic greater climate variation as well as any accompanied changes in agricultural farm management. However, accurate modeling of agricultural systems requires extensive knowledge of on-the-ground parameters, such as soil profiles for water and nutrient distribution, as well as a variety of crop specific physiological development data usually gained through field trials. This information can be difficult to obtain, as it requires labor and technical understanding to collect the appropriate data.

However, it will greatly benefit future planning if there is greater development of extension and on the ground research staff who are able to assist in collecting relevant soil and plant development data and in modeling cropping strategies to specific location variables. Simulation analyses conducted on specific production scenarios are especially useful in improving decision making particularly when performed in con-junction with local knowledge of potential environmental and socioeconomic challenges. The use of interdisciplinary research to consider the overall crop management system will allow for better adaptation method development and implementation.

Because farmers require economic incentives to be willing and able to adopt new practices, economic models that can predict threshold prices at which farmers begin to adopt environmental land-use practices or payments for ecosystem services can be highly effective in encouraging farmer adoption of diversified agricultural systems.

Stakeholder involvement and participatory research

Stake holder involvement and participatory research are often very useful tools in developing adaptation options that will be adopted by a local community because these methods recognize that knowledge often lies with the farmers in the field, and that local considerations should be integrated into long-term planning.

ROLE OF LEGUMES IN IMPROVING SOIL FERTILITY STATUS

Legumes and legume-inclusive manufacturing systems can play essential roles by means of turning in more than one offerings in line with sustainability principles. Indeed, legumes play central roles: (a) at food-system level, both for human and animal consumption, as a source of plant proteins and with an increasingly importance in enhancing human beings health; (b) at production-system level, due to the capability to fix atmospheric nitrogen making them potentially notably appropriate for inclusion in low-input cropping systems, and due to their function in mitigating greenhouse gases emissions; and (c) at cropping-system levels, as diversification vegetation in agro ecosystems primarily based on few important species, breaking the cycles of pests and diseases and contributing to stability in plant protein manufacturing in many areas of the world.

Legumes have probably a substantial position to play in enhancing soil carbon sequestration. They can also have considerable additional advantages beyond their significance involving nitrogen fixation and excessive protein feeds. These consist of advantageous impacts on biodiversity and soil quality. There is a great need for a strong focus on creating the role of legumes and their contribution to each the sustainable intensification of manufacturing and the livelihoods of small farmers in many parts of the world. Apart from their makes use of as food and fodder they have a very necessary position in retaining soil fertility by fixing atmospheric nitrogen and enhancing soil structures and adding organic matters. Moreover, it is generally used as an intercrop and covers plants, and sometimes, it is cultivated as emergency vegetation due to its brief life cycle. Since it requires low fertilizer and other inputs, this crop is relatively profitable in a most economical point of view. It also improves environmental quality by sequestrating carbon and mitigating other pollutants. Legumes are additionally a potential plant team in which some of the species having a capacity of remediating poisonous metals and organic pollutants.

Nitrogen fixation

Legume plant and seed tissue is distinctly high in protein. This can be without delay attributed to a legume's capability to supply most of its personal nitrogen requirement with the assistance of symbiotic Rhizobia microorganism residing in their roots. Inoculated with the applicable stress of Rhizobia bacteria, legumes can furnish up to 90% of their own nitrogen (N). Shortly after a legume seed germinates in the presence of Rhizobia microorganism in the soil, the bacteria penetrate the root hairs and cross into the root itself. The bacteria multiply, inflicting a swelling of the root to shape pale pink nodules. Nitrogen gasoline present in the soil air is then sure by the microorganism which feed on carbohydrates

Improve soil structure

The improvements are attributed to increases in more stable soil aggregates. The protein, glomalin, symbiotically along the roots of legumes and other plants, serves as a "glue" that binds soil together into stable aggregates. This aggregate stability increases pore space and tilth, reducing both soil erodibility and crusting.

Lower soil pH

Because inoculated, nodulated legumes acquire their N from the air as diatomic N rather than from the soil as nitrate, their net effect is to lower the pH of the soil. In greenhouse studies, alfalfa and soybeans lowered the pH in a clay loam soil by one whole pH unit. Legumes could lower the pH and promote increased plant-soil-microbial activity on soils with a pH above the range for optimum crop growth and development.

Biological diversity

Legumes contribute to an increased diversity of soil flora and fauna lending a greater stability to the total life of the soil. Legumes also foster production of a greater total biomass in the soil by providing additional N. Soil microbes use the increased N to break down carbon-rich residues of crops like wheat or corn.

Legumes and carbon sequestration

Enhancing C sequestration in the soil is linked to elevated biomass and hence to soil fertility. Raising fertility is perchance the most effective way of rapidly growing carbon sink capacity. Clearly, one way of doing this is through elevated addition of nitrogenous fertilizers. However, caution in the enormous use of nitrogenous fertilizers as a strategy to elevated productivity is excellent for a variety of reasons, consisting of the potential for other emissions. By contrast, the role of legumes in supplying nitrogen (N) through fixation is being increasingly more seen as important as an extra beneficial in terms of common GHG stability. The introduction of legumes and their higher utilization as section of a pasture improvement system are consequently probably to be worthy of serious consideration in many circumstances.

Reduction in greenhouse gasoline emissions

Legumes are also possibly to have a position to play in lowering GHG emissions from ruminant systems. An approach to decreasing methane emissions of current interest and supported by some initial evidence is the use of tannin containing forages and breeding of forage species with greater tannin content. Forage legumes such as *Lotus corniculatus* (birds foot trefoil) and *L. uliginosus* (greater trefoil) possess secondary metabolites acknowledged as condensed tannins in their leaves. They are no longer present on the leaves of white or purple clover but are existing in the inflorescences. Methane production values had been lower in housed sheep fed on purple clover and birds foot trefoil than on a ryegrass/white clover pasture. The emissions of nitrous oxide from soils improved linearly with the quantity of mineral nitrogen fertilizer applied and structures containing legumes produce lower annual nitrous oxide emissions, alfalfa and different legume vegetation need to be regarded differently when deriving national inventories of GHG from agriculture.

Legumes are soil-amendment crops with strong benefits on soil health and need to be an essential element of the farming systems. Legumes have positive effects on soil processes such as benefiting agro ecosystems, agricultural productivity, soil conservation, soil biology, SOC and N stocks, soil chemical and bodily properties, BNF, nitrous oxide (N_2O) emission, and nitrate (NO_3) leaching by means of lowering the need for chemical fertilizers. Above all, legumes are now utilized as soil nourishment agents. However, these benefits on soil health need to be quantified, and their mechanisms understood. Thus, incorporating legumes as a section of cropping systems is pertinent to higher soil fitness and productivity.

The potential for legumes to mitigate climate change

The concentrations rise, it has become an increasing number of necessary concerns to account for losses of CO_2 and N_2O arising from agriculture. Emissions of these gases may occur either directly as the result of farming activities (e.g., cultivation and harvesting) or circuitously for the duration of the production and transport of required inputs (e.g., fertilizers, herbicides, and pesticides). The plausible function of N_2-fixing legumes in lowering GHG emissions via direct effects on CO_2 and N_2O fluxes in the production of high-protein grain and forage will be in contrast to the functions of fertilizer N in the following sections. CO_2 emission is bobbing up from N fertilizer manufacturing and symbiotic N_2 fixation.

Role of legume vegetation on enhancing soil physical properties

Important soil physical properties are bulk density, porosity, combination stability, and texture. These properties are additionally associated with water-related methods including aeration, runoff, erosion, water maintaining capacity, and infiltration rate. Legume vegetation have a manageable to enhance physical properties of soil by being a soil conditioner and enhancing the physical residences. Leguminous cover crops have a tremendous effect on soil physical properties broadly speaking due to the manufacturing ability of large biomass which affords substrata for soil organic undertaking and soil organic matter. Furthermore, leguminous cover vegetation are grown to protect the soil from loss of plant nutrients and erosion, while green manure plants are grown for the motive of improving soil bodily properties. Moreover, some plants can physically modify the types of soil profile. Legumes additionally have an effect on soil shape by means of their impact on aggregation. Leguminous cover crops can expand or keep an appropriate soil C/N ratio and increase in preserving soil organic carbon stock. Legume plants often result in higher infiltration of water, due to direct effects of the crop residue in soil formation and aggregation.

Role of legume crops on improving soil chemical properties

Soil chemical properties for sustainability are connected with the capability to provide nutrients for crop and retaining/denaturing hazardous chemical compounds or factors to the agro ecosystem. Soil cation exchange capacity (CEC), pH, nutrient levels, and soil organic carbon concentration are the primary chemical elements used towards the evaluation of soil fertility. Soil chemical properties have been associated with leguminous crops, and thus, the particulars of a soil property are easily interpreted and permit a rapid enhancement of the soil chemical properties through N-fixation and root biomass. Legume-based rotation induces modifications in the pH of the rhizosphere sector of soil. Root exudation of legumes and change or release of organic acids on the epidermal cell of root surfaces can also enhance P availability. In addition, changes in pH are broadly recognized to affect the increase and undertaking of microorganisms, which are additionally necessary aspects in nutrient cycling processes. Leguminous green manure is a well-known generator of soil natural matter. Green manure, apart from increasing soil N, releases P, continues and renews the soil natural carbon, and improves soil chemical characteristics. Incorporation of legume residues is really useful to the soil for growing soil natural carbon awareness which is not only vital to agricultural productiveness however also to sequestration of C from atmospheric CO_2. When leguminous cover plants are used as green manure and incorporated into the soil, their residues make bigger availability of N, P, K, and trace elements to the succeeding plants due to the lowering of the soil pH brought about by the CO_2 produced in the process of decomposition.

CROP DIVERSIFICATION FOR IMPROVED WEED MANAGEMENT

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Introduction

Weeds can be defined as any plant that is objectionable or interferes with the activities or welfare of humans. In a crop production system, weeds compete for the same resources as the crops, such as water, nutrients, sunlight, and space, limiting crop productivity. Aggressive weed competition reduces crop yield significantly and adds further cost to crop production owing to their management. Yield loss due to weeds depends on several factors such as density, time of emergence, type of weed, and crop type. Globally, up to 40% yield loss because of weeds has been reported.

In developing countries, subsistence farming is the primary form of agriculture, and weeds are generally managed through hand-weeding. However, due to increasing urbanization, increased labor costs, and decreasing workforce in agriculture, people are moving towards using chemicals for controlling weeds. Over-reliance on herbicides to control weeds and injudicious use of herbicides has led to several issues such as herbicide-resistant weeds, herbicide drift, environmental and health problems, and extinction or population reduction of species. In addition to this, some weeds have developed resistance to multiple modes of action while others have (developed decreased sensitivity to herbicides. Both target-site and non-target-site mutations in the herbicide-resistant weeds have been reported. These observations indicate over-reliance on herbicides as a non-sustainable measure for weed control.

Increasing reports of crop damage because of herbicide drift in recent years. For instance, 2,4-dichlorophenoxyacetic acid (2,4-D) is one of the most used herbicides to control broad leaf weeds in agriculture; however, they often damage the neighboring 2,4-D sensitive cotton field resulting in the loss of millions of dollars. Further, increasing use of herbicides has led to the accumulation of agricultural contaminants such as arsenic, cadmium, lead, and mercury in soil and water resources. Over-dependence on herbicides may result in the increased frequency of herbicide resistance in weeds, water and soil pollution, and herbicide drift. Thus, to mitigate and/or eradicate ecological, environmental, and social externalities associated with intensive use of herbicides, it is imperative to design and promote alternative weed management approaches.

Increasing crop diversity can subject weeds to a greater number of stresses and reduce reliance on external chemicals for weed/pest control. Crop diversification can be defined as the conscious inclusion of functional biodiversity at the temporal and/or spatial levels to improve productivity and stability of ecosystem services. The concept of crop diversification is complex, and a diversified cropping system is more complicated with different crop combinations, unlike monoculture, where extensive farmlands are cultivated with one or two annual crops. Modern agricultural practices have simplified the agricultural systems to enhance the profitability of major crops or livestock. In contrast, a diversified cropping system focuses on creating sustainable, resilient, and socially just global food systems. Some of the examples of a diversified cropping system would be (i) multiple genotypes of the same crop or different crops grown in polyculture (ii) inclusion of legumes in otherwise cereal dominated systems and, (iii) temporal and spatial rotation of crops, including but not limited to cover crops, trap crops, hedgerows, fallow fields, etc.

There are certain set of rules on which crops to be chosen in a diversified farming system (for, e.g., Liebman and Dyck talks about strategies for crop rotation and intercropping in context of weed management). The consequences of diversification include, but are not limited to increased soil nutrient recycling, pest and disease suppression, enhanced water use efficiency, and pollination. Many of the previous studies have advocated the importance of crop diversification in sustainable agricultural production. However, knowledge of how different crop diversification techniques impact weed management and the constraints of adopting crop diversification in the modern agricultural context is lacking.

Crop Diversification Focused on Weed Management

Two general principles for weed management through crop diversification, (a) weeds should be subjected to various stress and mortality factors by using crop sequences containing different species and management practices, and(b) diversification methods should be designed to maximize the capture of light, nutrients, and water by crop, thus reducing the loss by weeds. These principles should be the foundation for any crop diversification methods (e.g., crop rotation, cover cropping, and intercropping). However, the objective of the diversification strategies is not to eliminate all the weeds, instead to control them. Weeds offer various ecosystem services, which sometimes are beneficial to crops and humans.

Crop Rotation

Crop rotation helps to reduce weed pressure and increase crop yield. Weed species in monoculture tend to adapt to management practices and cause yield reductions (e.g., herbicide resistance, early seed shattering, and crop mimicry). In crop rotations, weeds are subjected to diverse weed control methods (no-tillage/till or diverse herbicides, planting dates, fertilization regime), thus preventing weeds from adapting and surviving. Crop rotation diversifies the selection pressures on weeds by using alternative management tactics, alternating patterns, and timings of soil disturbance, light transmission, and nutrients. Therefore, crop rotation favors the establishment of diverse weed flora rather than dominated by one or few weed species, which in some cases leads to reduced input costs (e.g., herbicide usage).

Soil weed seed banks preserve propagules for the next generation with the traits such as genetic diversity, long-term seed dormancy, erratic germination, and herbicide resistance/susceptibility. These traits allow weeds to thrive in diverse conditions, including stress from management practices and harsh environments. Crop rotation is one of the various approaches to manage soil seed banks.

Crop rotation with a non-host of parasitic plants can help reduce the seed bank of parasitic weeds. The non-host crop is also known as a trap crop, which tricks parasitic seeds to germinate while not causing any crop loss. Crop rotation as one of the most effective methods to reduce Striga infestations in corn and increase corn yields. Crop rotation can also help prevent herbicide resistance by promoting the usage of herbicides with diverse modes of action. Herbicide-resistant risk is greater where no crop rotation is practiced as compared to fields with crop rotation. Understanding the ecology of weeds and adapting to cultural practices can promote sustainable weed management with less dependency on herbicides.

Intercropping

Intercropping is an integrated weed management practice in which two or more crop species or genotypes are cultivated together and coexisting for a time. It is commonly used in countries with low-input (high-labor) and resource-limited agricultural systems on a small piece of land. Intercrops can broadly be divided into three types:

(a) Relay intercropping (planting a second crop before the first crop is mature), (b) mixed intercropping (simultaneously growing two or more crops), and (c) strip cropping (growing two or more crops simultaneously in strips). Each type has its benefits, but overall intercropping compared with monocrops provides a similar yield with reduced inputs, pest control (weeds, diseases, and insects), and stable aggregate food yields per unit area.

In the case of weed management, intercropping reduces weed pressure and allows crops to proliferate. It works based on the principle of resource partitioning among co-occurring crop species with different resource acquisition strategies, allowing crops to use resources better and leaving less space, water, and nutrients to weeds. Inter- cropping creates a situation with the increased availability of common limiting factors to the crop. Resource partitioning is more likely to occur when functionally different crops are combined. For example, cereals intercropped with legumes can improve nitrogen fixation, better weed control, and high yields

Apart from the resource partitioning, intercropping may involve allelopathic interactions, which is environmentally friendly and provides economic weed control. The mechanism of allelopathy involves both inhibitory and stimulatory relations among neighbor plants, directly affecting growth and development. Among cultivated crops, sorghum species are extensively studied for their allelopathic potential and characterization of allelochemicals associated with weed suppression. Several studies have indicated that intercropping sorghum with crops provides better weed control and higher yields than their monocrops. Allelopathy is also associated with other field crops such as corn, oats (Avena sativa L.), pearl millet (*Pennisetum glaucum* L.), sesame (*Sesamum indicum* L.), sunflower, and soybean. All of the crops mentioned above showed weed suppression when intercropped with other cereals/legumes/oilseeds. Striga spp are among the notorious weed parasites, which can cause severe damage to crops. Intercropping is one of the effective methods to manage Striga for small-scale subsistence farmers. Allelopathic compounds from the Brassicaceae family are proven to be useful for the control of Orabanche spp.

Cover Crops

Cover crops are crops planted between the growing seasons to improve soil health, reduce soil erosion, suppresses weeds and other pests. Cover crops suppress weed growth by multiple mechanisms such as competition for light, space, water, and nutrients. After the termination of the crop, it forms a mulch layer on the soil surface, which is proven to reduce weed germination, emergence, and establishment. Furthermore, cover crops and associated mulch have been shown to release allelochemicals, which further suppress weed growth.

Cover crops require adequate soil water, moderate temperature, and good seedbed preparation for quick emergence and robust growth. Cover crops are part of an integrated weed management practice, preventing and managing herbicide-resistant weeds

The diversity and size of the weed seed bank strongly influence the success of weed management practice. Cover crops can reduce weed seed bank by preventing propagule production, reducing seedling establishment, early/delay emergence. Long term use of the cover crop before cash crops can help to deplete weed seed bank

Major Constraints to Adoption of Crop Diversification in Modern Agriculture

A large-scale monoculture agriculture system has deeply entrenched across the world ensuing difficulty for any alternative production system such as diversified farming to flourish. Reluctance among the commercial farmers in adopting crop diversification could be because of not prioritizing the importance of ecology or the lack of knowledge about diverse farming models and relevant scientific mechanisms governing their several advantages. In the absence of proper knowledge and skills, it is evident for the farmers to be more doubtful of the economic success of relatively complex farming systems on a large-scale. In addition, the current agricultural technologies development is mostly centered towards sole-crop farming. For instance, plant breeding tools focusing on improving a few key traits have contributed to increased specialization and reduced genetic diversity. Moreover, too much focus on plant improvement against biotic/ abiotic stresses is likely to limit the willingness of the farmers to adopt a diversified cropping system to develop crop resilience.

Although diversified farming uses agricultural inputs more judiciously and could be cheaper in the long run, small-scale farmers may struggle to establish a diverse agriculture farm as it requires more resources at the beginning. The diversified cropping system, farmers experienced an increase in the types of farm activities, requiring broad knowledge, skills, equipment, manpower, and advisory services to run, and needing more years to return the initial investments. Therefore, farmers with no other alternative income source are unlikely to take risk towards the diversified approach. More naturally grown agricultural products seem to get a high price, and price risk is reduced with the diversification. However, farmers may experience difficulty in transportation and marketing for a small number of diverse products.

COMPANION PLANTING AND INSECT PEST CONTROL

Crop monocultures encourage the multiplication and spread of pest insects on massive and uniform crop. Numerous studies have evaluated the impact of plant diversification on pests and beneficial arthropods population dynamics in agricultural ecosystems and provided some evidence that habitat manipulation techniques like intercropping can significantly influence pest control. Application and mechanisms of biodiversity in agricultural systems are enhances the good pest management.

To avoid environmental pollution, health problems and species loss caused by the over resilience on synthetic insecticides, exploration of multi-function agricultural biodiversity that enhances pest management is necessary in sustainable agricultural system. The main reason for this lies in the fact that modern agriculture achieved significant advances in terms of agro ecosystem productivity that come at the price of sustainability. This is because modern growing systems imply the simplification of the structure of the environment over large areas of land, replacing natural plant diversity with only a limited number of cultivated plants in monocultures.

Increasing crop species diversity via intercropping is a simple and effective measure that offers advantages at reducing pest densities. Inter cropping or mixing different crops as a traditional agricultural technique is used for preventing pest infestation in different world geographical areas. The plant components of inter cropping system do not necessarily have to be sown at the same time, but they should be grown simultaneously for a substantial part of their growth periods. There are several different crop arrangements in intercropping viz., mixed intercropping, row intercropping, strip intercropping and relay intercropping.

Intercropping influence pest control

The advantage of intercropping systems is their ability to reduce the incidence of pests due to increased botanical diversity. Compared with a monoculture, adding more plant species to a cropping system can affect herbivores in two ways. Firstly, neighbouring plants and microclimatic conditions is altered and secondly the host plant quality e.g. morphology and chemical content, is also altered. Plants in intercropping system may sustain lower herbivore populations because herbivores have difficulty in finding them, leave them more quickly or have difficulty in relocating them after leaving.

Components of intercropping system suffer significantly less damage from insects compared to their cultivation as sole crops, which has positive impact on yield. Significantly lower population of insects was observed on the cowpea – *Vigna unguiculata (L.)* Walp intercropped with maize than on cowpea as a sole crop. Maize cultivated with cassava – *Manihot esculenta* Crantz had significantly lower infestations by insects.

Mechanisms explaining reduced pest incidence in intercropping

In order to explain reduced pest presence in intercropping system several mechanisms has been proposed.

Olfactory stimuli

Visual and olfactory signals from non host neighbors can have positive impact on focal plants by reducing their attractiveness for herbivores. Insects are known to respond to different chemical signals released from plants. Volatile chemical signals emitted by plants represent important source of information for herbivores to find host plants. As the main herbivorous insects of many crops, aphids are highly sensitive and able to detect changes in small changes in plant status. Aphids are organisms extremely sensitive to changes in the quality and physiological status of their host plants, therefore for this purpose they considerably rely on chemical information in the process of host location and selection. The diversity of olfactory stimuli emanating from poly cultures might mask the olfactory cues used by monophagous herbivores to find their host plants or otherwise confuse or repel these herbivores. Volatiles from non host plants may interfere with the attractiveness of focal plants, resulting in “olfactory masking”. Female insects will spend more time for searching a suitable host plant in intercropping and oviposit fewer eggs on the focal plants. Understanding the chemical interactions between plants and insects is of particular importance not only for environmentalists but also for the development of new strategies in plant protection based on the natural occurring phenomena.

Visual Stimuli

Neighboring plant architecture may play an important role in their ability to mask, repel, confuse or disrupt focal plant herbivores. This may be achieved by visually perceived signals from non host plants in diversified habitats. Non-host plants may interfere herbivores access simply by visually blocking the focal plant and reducing the likelihood of detection. Herbivore movement patterns, rather than natural enemies, are often more important in accounting for reduced *Aphis fabae* abundance on bean plants intercropped with maize. Neighboring plants can also act as attractant for herbivores reducing their colonization and damage on focal plant.

Volatile interaction between plants change host plant quality

Chemical interaction between plants can affect insects behavior on their host plants. Different plant species in intercropping systems often compete for available resources with consequences for plant grown and chemical composition, which in turn could affect host plant finding and acceptance by herbivores.

Presence of natural enemies

Presence of natural enemies play important role in suppression of herbivores in agro ecosystems. Specific crop habitats are considered to play important role in survival of natural enemies of herbivores. It is known that increased plant species diversity support diversity and abundance of natural enemies as well as their activity. Intercropping provides additional resources such as food and shelter that enhance abundance and effectiveness of natural enemies. Survival and reproduction of general and special list of beneficial insects requires provision of additional resources such as pollen and nectar that are scarce in monoculture. Recent studies on the effect of plant diversity on generalist natural enemies have shown their increased abundance in more diverse growing systems. Mixing of different plant genotypes within same species may influence lady bird beetle habitat preference. It has been shown that lady bird beetle positively respond to increased botanical diversity. Reduced pest incidence in inter cropping system was attributed to increased population of natural enemies. The foraging behaviour of *Coccinella* is also influenced by habitat characteristics, including the identity and diversity of plants. In growing systems where intercrop provides a permanent vegetation cover, the interaction between pests and its natural enemies can more easily come into equilibrium. For this reason, biological control is more successful in perennial crops than in annual crops. Performance of natural enemies is enhanced in mixed cropping systems, because these systems provide a variety of microhabitats and alternative prey. However, parasitoids benefited from more diversified systems since the flower resources provide them additional source of food. In review of different studies that compared parasitoid density and parasitism rates reported that in two third of studies were more abundant and attacked more herbivores in intercropping system than in monoculture.

Effect of intercropping system on pest levels

Crop		Pest reduced	Reference
Main crop	Intercrop		
Sorghum	Red gram	Earhead bug	Raheja (1973)
Sorghum	Cowpea	*Chilo partellus*	Balasubramanian (2000)
Pigeon pea	Sorghum	*Empoasca kerri*	Sekhar et al (1997)
Green gram	Sorghum	*E. kerri*	Sekhar et al (1997)
Ground nut	Sorghum	*E. kerri*	Sekhar et al (1997)
Pigeon pea	Sorghum	*H. armigera*	Mohamed and Rao (1998)
Chickpea	Wheat / Mustard / Safflower	*H. armigera*	Das (1998)
Sugarcane	Green gram / Black gram	Early shoot borer	Rajendran et al. (1998)

In diversified cropping systems insect pest impact has been regularly reduced. Intercropping has proven to be simple and efficient ecological approach that modifies local environment and favor reduced pest pressure and enhanced activity of natural enemies. Chemical interactions between plants can affect herbivores and reduces their performance. It is obvious that modification of single practices such as cultivar choice in diversified cropping system can significantly impact herbivores and their natural enemies.

Companions that disrupt host location by pests

Herbivorous insects use a wide variety of means to differentiate between host and non-host plants. Consequently, host-finding behavior of the target's pests plays a key role in selecting plants. Typically, host plant selection by insects is a catenary process involving sequences of behavioral acts influenced by many factors. These can include the use of chemical cues, assessment of host plant size, and varying abilities to navigate and identify hosts among the surrounding vegetation. Therefore, both visual and chemical stimuli play key roles in host plant location and eventual acceptance.

Companions that draw pests away from the protection target

Once pests are concentrated in the trap crop the pests can be removed by different means, such as burning or tilling-under the trap crop or by making insecticide applications to the trap. A highly-effective trap crop can bring a relatively large number of pests into a relatively small area, such that pest management within the trap crop requires coverage of less ground than if the entire planting of the protection target had to be treated. Even if left unmanaged through other means, pests feeding within the trap are not damaging the protection target. Because trap crops are more attractive to the pest, they are usually rendered unmarketable due to pest damage. This means that to be economically viable, the cost of establishing and maintains the trap crop must be equal or exceed the value of crop protection within the protection target.

Plants that repel

Plants with aromatic qualities contain volatile oils that may interfere with host plant location feeding, distribution and mating, resulting in decreased pest abundance. Moreover, certain plants contain chemical properties which can repel or deter pest insects and many of these products are used to produce botanical insecticides. For example, pyrethrum obtained from dried flower of the pyrethrum daisy (*Chrysanthemum cinerariaefolium*) neem extracted from seeds of the Indian neem (*Azadirachta indica*) and essential oils extracted.

Plants that mask

Companion plants may release volatiles that mask host plant odor interfering with host plant location. For example, host location by cabbage root fly was disrupted when host plants were surrounded by a wide variety of plants including weeds and marketable crops such as peas (*Pisum sativum*). Cmpanion plants contain different chemical profiles, it is unlikely that all would be able to mask host plant odors.

Plants that camouflage or physically block

In addition to protecting crops with olfactory cues, companion plants may also physically and visually camouflage or block host plants. The appropriate / inappropriate landing theory proposed that green surface surrounding host plants may disrupt host plant finding. The appropriate/inappropriate landing theory was originally inspired from studies exploring the oviposition behavior of cabbage herbivores and found that reduced damage in intercropping systems were attributed to a disruption of oviposition behavior. This can occur when insects land on a companion plant instead of the target crop before or during oviposition.

Combination of companion planting techniques

In some systems, different companion planting methods have been combined to work synergistically and improve pest control. Here, the push (repellent companion plants) drives the pest insect away from the target crop, while the pull (trap crop) simultaneously lures the pest.

Constraints and challenges

Incorporating companion plants into pest management strategies is not without challenges. Farmers often face logistical constraints when incorporating companion plants into their field designs. For example, modern agriculture techniques and equipments are not conducive to growing multiple crops in one field. Furthermore, companion plants may hinder crop yield and reduce economical benefits. Decreased yields can often be attributed to competition for resources by incorporating inappropriate companion plants. In certain cases, vegetation diversification can diminish the impacts of biological control. Generally, greater habitat diversity leads to a greater abundance of prey and host species. For instance improved diversity can lead to reduced biological control by generalist predators which can be influenced by the greater diversity and abundance of alternative prey.

Therefore, choosing which type of companion plant to incorporate in a diversification scheme is challenging. For example, plant phenology, attractiveness and accessibility of the flowers to natural enemies and pest species will play a key role in plant selection. However, it is possible to minimize the reductions in economic returns within companion planting schemes. It is important to use plants that can provide a satisfactory economic return, if possible, as compared to the target crop planted in monoculture. In conservation biocontrol, to reduce negative impacts from biocontrol antagonists or the targeted pest suggested using specific resources that can selectively benefit key natural enemies. Overall, whether companion plants control pests through bottom-up or top-down mechanism, their impact will depend on companion plant selection. This emphasizes the significance of finding the "right type" of diversity that combines species that complement one another in ecologically-relevant ways. Designing companion planting schemes pose several impending issues. For instance, optimal distances between the companion plant and the target crop needs to be determined before specific recommendation can be made.

Companion Planting and Insect Pest Control

Companion planting is a well-known strategy to manage insect pests and support a natural enemies population through vegetative diversification. Trap cropping is one such type of special companion planting strategy that is traditionally used for insect pest management through vegetative diversification used to attract insect pests away from the main crops during a critical time period by providing them an alternative preferred choice. Trap not only attracts the insects for feeding and oviposition, but also acts as a sink for any pathogen that may be a vector. Optimal trap cropping over an artificially released natural enemy-based biological control could be an attractive remedy for natural enemies in cropping systems. Besides, many trap crop species can conserve natural enemies. This secondary effect of attracting natural enemies may be an advantage compared to the conventional means of pest control. However, this additional consideration requires a more knowledge-intensive background to designing an effective trap cropping system.

Traditional companion planting which involves planting different types of plants together or in close proximity makes many such statements, often based on little more than folklore. In recent decades, however, scientists have found that in fact there are definite benefits to adding diversity to field, primarily because certain plants attract and support beneficial insects that either help control pests or help pollinate the crops.

Use of companion planting for insect-management

Companion plants provide a desirable environment for beneficial insects and other arthropods especially those predatory and parasitic species which help to keep pest populations in check. These plant may be insectary or attractant plants both for beneficial (intercrop/attractant plants) and harmful insects (as trap plants) as well as repellent plants (used as intercrop).

Push-pull habitat manipulation for control of maize stem borers and the witch weed Striga has been very successful. “Pull”: The grasses are planted in the border around the maize and sorghum fields where invading adult moths become attracted to chemicals emitted by the grasses themselves. Instead of landing on the maize or sorghum plants, the insects head for what appears to be a tastier meal. These grasses provide the “pull” in the “Push-Pull” strategy. They also serve as a haven for the borers’ natural enemies. Good trap crops include well-known grasses such as Napier grass (*Pennisetum purpureum*). Napier grass has a particularly clever way of defending itself against the pest on slaught: once attacked by a borer larva, it secrets sticky substance that physically traps the pest and effectively limits its damage. The natural enemies lurking among the grasses go into action and dispatch the borers in both maize or sorghum and grass hosts plants. ‘Push’: The “push” in intercropping scheme is provided by the plants that emit chemicals (kairomones) which repel stem borer moths and drive them away from the main crop (maize or sorghum). The best candidates discovered so far with the repellent properties are members or leguminous genus Desmodium spp. Desmodum is planted in between the rows of maize or sorghum. Being a low-growing plant it does not interfere with the crops growth and, furthermore, has the advantage of maintaining soil stability, improving soil fertility through enhanced soil organic matter content and nitrogen-fixation. It also serves a highly nutritious animal feed and effectively suppresses striga weeds. Another plant showing good repellent properties is **molasses grass (Melinis minutiflora),** a nutritious animal feed with tick-repelling and stem borer larval parasitoid attractive properties.

Pest Management

In this “Push-Pull” strategy under the ecological engineering system the following are the considerations for maize stem borer and striga management:

1. The forage grasses, *Pennisetum purpureum* (Napier grass) and *Sorghum vulgare* sudanense (Sudan grass), attract greater oviposition by stem borers than cultivated maize.
2. Non-host forage plants Desmodium uncinatum (silver leaf) repel female stalk borers (Chilo sp).

3. Napier grass also has its own defense mechanism against crop borers: when the larvae enter the stem, the plant produces a gum-like substance kills the pest.
4. Sudan grass also increases the efficiency of the natural enemies (the parasitism rate on larvae of the spotted stem borer, Chilo partellus.
5. Intercropping maize with the fodder legumes *Desmodium uncinatum* (silver leaf) reduced infestation of parasitic weed *Striga hermonthica.*

Why did diversity?

- Resources from flowers, i.e. nectar and pollen:
  Attract and support predators and parasitoids (natural enemies) for pest control. Some tiny parasitoids require nectar or another source of sugar, and abundant nectar improves their survival and increases reproduction. Syrphid or hover flies feed on nectar and pollen, and lay hundreds of eggs near soft bodies insects such as aphids. The eggs hatch into larvae that are voracious feeders on those small pests. Lacewings and lady bird beetles are also attracted to flowers and can effectively control aphids.
- Diversity attracts and support pollinators, providing nectar and pollen that bees and butterflies need.
- Some flowers support alternate prey for natural enemies. For example, marigolds often support numerous tiny pest insects called thrips, which in turn are fed on by tiny voracious predatory bugs, Orius species, also known as minute pirate bugs. The Orius may also patrol nearby crop plants, reducing populations of soft-bodies pests. Marigolds are also well-known for their ability to control nematodes due to the toxic chemicals exuded by their roots; however, this works better when marigolds are planted as a cover crop, with their residues tilled into the soil before the crop is planted.
- The presence of different plant species grown together can disrupt the ability of pests to find their host plants. Plant-feeding insects. especially those that only feed on one or a few types of plants, find their host plants by sight and smell, and these cues can be disrupted by surrounding plants, especially aromatic or bushy plants.
- Adding ground-level complexity, for example strips of grass, weeds, or cover crops, can increase populations of ground-dwelling generalist predators, such as ground beetles and spiders, which can feed on plant-feeding insects, especially those that spend a part of their lives in the soil. Grassy “beetle banks” also provide sheltered overwintering habitat for insect predators.

- Caution: Diverse plantings increase populations of natural enemies, this does not always translate into fewer pests on the desired crop plant, since the predators and parasitoids may not disperse to where they are needed. You will still need to check your plants frequently for unwanted pests, and control them in some other way if the good bugs are not effective enough!.
- In addition, the added plants will compete with the crop for light, water and nutrients and therefore crop yield may be reduced compared to a monoculture of the crop. Select companion plants that are not overly competitive with the main crop.
- Other examples where diverse plantings make sense. Plants with different characteristics can be used to support soil nutrition and better yield in a small space. For example, legumes, such a alfalfa, clover, peas and beans, fix nitrogen and can be planted in rotation with non-legumes; deep-rooted plants can be grown with shallow-rooted plants; and sun-loving plants can provide shade for shade-loving plants and also help to reduce weeds.

The Companion Planting has many benefits

- **Help each other grow:** Tall plants, for example, provide shade for sun-sensitive shorter plants.
- **Prevent pest problems:** Plants like onions repel some pests. Other plants can lure pests away from more desirable plants;
- **Attract beneficial insect :** Every successful garden needs plants that attract the predators of pests.
- **Use garden space efficiently:** Veining plants cover the ground, upright plants grow up. Two plants in one patch; use garden soil efficiently.
- **Help reduce disease inoculums efficiently:** Cereal crops like sorghum, maize and rice for wilt causing pathogens.
- **Help enhance soil fertility:** leguminous crops used as inter or mulch crops.
- **Help reduce weeds:** maize, pigeon pea, mulch crops
- **Protect from heat, wind and even winter :** Tall perennial plants planted on the border.
- **Repel insect-pests**
- **Trap insect-pests**

To utilize the benefits of companion plants in crop diversification which ultimately help reduce the insect-pests and improve plant health in different ways of planning can be adopted depending upon the purposes, nature of the crop plant and the strategy for the management of specific agriculture problem.

SPECIAL FOCUS ON CROP DIVERSIFICATION IN DELTA REGION

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Geographical distribution of area

Cauvery Delta Zone (CDZ) lies in the eastern part of Tamil Nadu. It is bounded by the Bay of Bengal on the east and the Palk straight on the south, Trichy district on the west, Perambalur, Ariyalur districts on the north west, Cuddalore district on the north and Puddukkottai district on the south west. CDZ has a total geographic land area of 14.47 lakh ha. The erstwhile Thanjavur district (comprised Thanjavur, Thiruvarur, Nagapattinam) occupies 57 percent of CDZ followed by Trichy, Ariyalur, Cuddalore and Pudukkottai districts.

Cauvery Delta Zone (CDZ) is broadly divided into three regions based on the irrigation system.

1. Cauvery System comprising of Kumbakonam, Mayiladuthurai and Sirkazhi sub divisions and parts of Papanasam and Thanjavur sub divisions. In this region, the soil is alluvial clayey texture and the ground water potential is good.

2. Vennar System consisting of Nagapattinam, Thiruthuraipoondi and Nannilam sub divisions. The soil is heavy clay with poor ground water potential. In coastal areas, the texture is sandy and water logging is a common problem.

3. Grand Anaicut Canal System comprising of Orathanad and Pattukottai subdivisions and parts of Thanjavur and Mannargudi sub divisions. The soil is sandy loam with good drainage.

Rainfall pattern

The rainfall distribution plays a vital role in deciding the cropping pattern in the CDZ. The normal rainfall during South-West monsoon (June - September) ranges between 250 to 325 mm out of which June and July contribute 40 to 50 mm each and August and September contribute 100 to 125 mm each. The temperature and wind velocity are high leading to high evaporation. Bright sunshine prevailing during this period is highly favorable for rice production and the yield is also higher compared to Thaladi or Samba crop

Principal crops

In this zone, rice is the principal crop. In the rice based cropping system, it is either single or double cropped. Pulses- blackgram and greengram are next importance grown in the rice fallows throughout the delta region from January onwards. Gingelly is also sown in April in prepared fields subsequent to summer showers. Vegetables like brinjal, chillies and greens are grown during summer months in limited area in the well drained fertile lands depending upon the underground water source. In light clay loamy soils under garden land condition is brought out where crops like groundnut, maize, gingelly and irrigated pulses are altered. Banana, sugarcane and ornamentals like jasmine, rose, chrysanthemum, crossandra and neerium are the annuals occupying the land for more than one year for the successive returns. Coconut gardens, bamboo and wood lots are scattered in the delta in different densities. Mango, jack, citrus, guava, pomegranate, custard, apple etc. are the more prevalent fruit trees in addition to cashew in specific pockets.

Existing Cropping Pattern

Rice dominates in the cropping systems of CDZ. It is understandable that with North East monsoon rains pouring at high intensity for short spells coupled with flat slopes and heavy soil, rice is the only ideal crop for the Thaladi / Samba season. The practice of double cropping of rice in Kuruvai (June – September) and Thaladi (October – February) seasons is on the increase in the filter point / bore well irrigated areas because of the development of short duration high yielding rice varieties for Kuruvai season. Weather being favorable during this season, Kuruvai rice is the main crop of rural economy of the Delta. But the double cropped lands extending over 1.6 lakh ha have been subjected to lot of hardship in the past years due to uncertainty in the release pattern of Cauvery canal water. The delay in receipt of canal water beyond June 12th cause delay in planting of kuruvai rice crop and consequent damage by North-East monsoon rains at harvest. The delay in first crop harvest naturally leads to postponement of Thaladi planting and early closure of canal many times results in complete drying of Thaladi rice during some years. There has been an increase in the area under summer crops utilizing the soil residual moisture and underground water through tube wells.

Cropping pattern suggested for different weather situations

1. Thanjavur district

Mean annual rainfall (mm) -1045.5

Cold weather period (Jan.-Feb) -47.1

Summer (March-May) -110.7

South West monsoon season (June-Sept) -342.0

North East monsoon season (Oct.-Dec.) -545.7

a. Command areas: alluvial soils

Existing

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)
Rice (Aug.-Jan.) - groundnut (Jan.-April) – gingelly (April-June)
Rice (Aug.-Jan.) - pulses / gingelly/ cotton (Jan.-April)
Sugarcane - ratoon sugarcane (Feb.-Dec.) – 2 years rotation

Normal year

Maize / pulses / vegetables (June-Sep.) - rice (Oct-Jan.) - pulses / cotton /gingelly/ sunflower (Feb-May)
Sugarcane - ratoon sugarcane (Feb.-Dec.) - 2 years rotation
Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)

Moderate drought year

Maize / clusterbean / lab lab / bhendi /pulses / gingelly/ green manure (June-Sep.) - rice (Aug.-Feb.) - pulses / cotton / sunflower (Feb.-May)
Coleus* / *Periwinkle**/ senna* (Sep.-Jan.)

Severe drought year

Millets / green manure / gingelly (June-Sep.) - maize / fodder (Oct.-Feb.) - pulses (Feb.-May)

b. Well irrigated areas (filter point well): alluvial and laterite soils

Existing

Rice (Aug.-Dec.) - groundnut (Dec.-March)
Vegetables (June-Sep.) - rice (Oct.-Feb.)

Normal year

Banana (June-May) - ratoon banana (May-June) -(drip-Fertigation) - 2 years rotation
Vegetables (June-Sep.) - rice (Oct.-Jan.) - pulses (Feb.-April)
Vegetables / onion (June-Sep.) - rice (Oct.-Jan.) - maize / pulses (Feb.-May)
Gloriosa* (2 year rotation) / coleus*
Flower crops (June planting)

Moderate drought year

Maize (Aug.-Dec.) - gingelly/ soybean (Dec.-Mar.)
Pulses / groundnut / gingelly (June-Sep.) - rice (Oct.-Feb.) - sunflower / maize (Feb.-May)

Severe drought year

Clusterbean / lab lab / bhendi (July-Dec.) - watermelon / cucumber (Jan.-April)
*Periwinkle**/ senna* (Jun-Sep.)
Pulses / green manure (June-Sep.) - upland rice (Oct.-Feb.)

2. Thiruvarur district

Mean annual rainfall (mm) - 1124.7
Cold weather period (Jan.-Feb) - 57.3
Summer (March-May) - 100.2
South West monsoon season (June-Sept) - 301.8
North East monsoon season (Oct.-Dec.) - 665.4

a. Command areas: alluvial soils

Existing

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly(Feb.-May)
Rice (Aug.-Jan.) - groundnut (Jan.-April) -gingelly(April-June)
Rice (Aug.-Jan.)-pulses/sesame/cotton (Jan.-April)
Sugarcane -ratoon sugarcane (Feb.-Dec.) - 2 years rotation

Normal year

Maize/pulses/vegetables (June-Sep.) - rice (Oct.-Jan.) - pulses / cotton / gingelly/ sunflower (Feb.-May)
Sugarcane - ratoon sugarcane (Feb.-Dec.)
Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)

Moderate drought year

Maize / clusterbean / lab lab / bhendi / pulses/ gingelly/green manure (June-Sep.) - rice (Aug.-Feb.) -pulses / gingelly/ cotton (Feb.-May)
Coleus* / *Periwinkle**/ senna*

Severe drought year

Millets / green manure / gingelly (June-Sep.) – upland rice / maize/fodder (Oct.-Feb.) - pulses / sunflower (Feb.-May)

b. Well irrigated areas (filter point well): alluvial soils

Existing

Rice (Aug.-Dec.) – groundnut (Dec.-Mar.) vegetables (June-Sep.) – rice (Oct.-Feb.)

Normal year

Pulses/groundnut/gingelly (June-Sep.) - rice (Oct.-Feb.) - groundnut / greengram/pulses (Feb.-May)
Rice (Aug.-Dec.) – groundnut (Dec.-Mar.) vegetables (June-Sep.) – rice (Oct.-Feb.)

Moderate drought year

Maize (Aug.-Dec.) - sesame/soybean (Dec.-March)
Pulses/groundnut/gingelly (June-Sep.) - rice (Oct.-Feb.) - sunflower / maize (Feb.-May)

Severe drought year

Pulses/sesame/green manure (June-Sep.)-upland rice (Oct.-Feb.) pulses/green manure (Feb.-May)

3. Nagapattinam district

Mean annual rainfall (mm) -1333.8
Cold weather period (Jan.-Feb) -80.3
Summer (March-May) -93.0
South West monsoon season (June-Sept) -274.1
North East monsoon season (Oct.-Dec.) -886.4

a. Command areas: alluvial and sandy soils

Existing

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)
Rice (Aug.-Jan.) - groundnut (Jan.-April) – gingelly (April-June)
Rice (Aug.-Jan.) - pulses/sesame/cotton (Jan.-Apr)
Sugarcane – ratoon sugarcane

Normal year

Maize/pulses/vegetables (June-Sep.) - rice (Oct.-Jan.) - pulses / cotton / gingelly/ sunflower (Feb.-May)
Sugarcane – ratoon sugarcane - 2 years rotation
Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)

Moderate drought year

Maize / clusterbean / lab lab / bhendi / pulses / sesame/green manure (June-Sep.) - rice (Aug.-Feb.) -pulses (Feb.-May)
Coleus* / *Periwinkle**/ senna* (June – Nov.)

Severe drought year

Millets / green manure / gingelly (June-Sep.) – maize/fodder (Oct.- Feb.) - pulses (Feb.-May)

b. Well irrigated areas (filter point well): alluvial and sandy soils
Existing

Rice (June.-Sept.) – rice (Oct.-Feb) - pulses (Feb-April)

Normal year

Rice/pulses/groundnut/gingelly (June-Sep.) - rice (Oct.-Feb.) – groundnut / greengram/pulses (Feb.-May)
Rice (June.-Sept.) – rice (Oct.-Feb) - pulses (Feb.-April)

Moderate drought year

Maize (Aug.-Dec.) - sesame/soybean (Dec.-Mar.)

Pulses/groundnut/gingelly (June-Sep.) - rice (Oct.-Feb.) - sunflower / maize (Feb.-May)

Severe drought year

Pulses/sesame/green manure (June-Sep.) - upland rice (Oct.-Feb.) - pulses/green manure(Feb.-May)

4. Trichirapalli district

Mean annual rainfall (mm) -759.3

Cold weather period (Jan.-Feb) -23.8

Summer (March-May) -109.1

South West monsoon season (June-Sept) -270.3

North East monsoon season (Oct.-Dec.) -356.1

a. Command areas: alluvial soils

Existing

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)

Rice (Aug.-Jan.) - groundnut (Jan.-April) – gingelly (April-June)

Rice (Aug.-Jan.)-pulses/sesame/cotton (Jan.-April)

Sugarcane - ratoon sugarcane (Dec.-Nov.) - (2 years rotation)

Normal year

Maize/pulses/vegetables (June-Sep.) - rice (Oct.-Jan.) - pulses / cotton / gingelly/ sunflower (Feb.-May)

Sugarcane - ratoon sugarcane (Dec.-Nov.) - (2 years rotation)

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)

Moderate drought year

Maize/vegetables/pulses/sesame/green manure (June-Sep.) - rice (Aug.-Feb.) - pulses / senna* (Feb.-May) Coleus* / *Vinca rosea* / senna* (June-Nov.)

Pearl millet / fodder sorghum (June-Sep.) - upland rice (Oct.-Jan.) - pulses / senna* (Feb.-May)

Severe drought year

Pulses (June-Sep.) - sunflower / coriander / cotton (Oct.-Feb.) – fallow

Millets/green manure / gingelly (June-Sep.) - maize / fodder (Oct. -Feb.) - pulses (Feb.-May)

b. Well irrigated areas: red, laterite, black and alluvial soils Existing

Rice (Aug.-Jan.) - groundnut (Jan.-April)
Banana (Jan.-Dec.) - ratoon banana (Jan.-Dec.) - rice (Dec.-April)
Vegetables (June-Sep.) - rice (Oct.-Feb.)

Normal year

Banana (June-May) - ratoon banana (May-June) (Drip-Fertigation)
Vegetables (June-Sep.) - rice (Oct.-Jan.) pulses (Feb.-April)
Vegetables/onion (June-Sep.) - rice (Oct.-Jan.) - maize / pulses (Feb.- May)
Gloriosa - (2 years rotation)
Coleus* (June-Oct)-rice (Nov-Feb.)-pulses (Feb-May)
Rice (Aug.-Jan.) - groundnut (Jan.-April)

Moderate drought year

Maize (Aug.-Dec.) - sesame/soybean (Dec.-March)
Fodder / pulses/ green manure (Aug.-Dec.) -gingelly/ groundnut / sunflower / sorghum / pearl millet (Dec.-March)

Severe drought year

Clusterbean / lab lab / bhendi (July-Dec.) - water melon/cluster bean/cucumber (Jan.-April)
*Periwinkle**/ senna* (Jun-Sep.)

c. Rainfed areas: red, black and laterite soils

Existing: Groundnut + redgram (Oct.-Feb.)
Normal year: Groundnut + redgram (Oct.-Feb.)
Green chilli/cluster bean / bhendi (Oct.-Feb.)
Moderate drought year: Sorghum/millets + pulses /gingelly/cucurbits (Oct-Feb)
Severe drought year: Fodder sorghum / minor millets/fodder/coriander (Oct.-Feb.)

5. Ariyalur and Perambalur district

Mean annual rainfall (mm) -949.0
Cold weather period (Jan.-Feb) -33.8
Summer (March-May) -116.0
South West monsoon season (June-Sept) -349.6
North East monsoon season (Oct.-Dec.) -449.6

a. Command areas: heavy clay soils

Existing
Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)
Rice (Aug.-Jan.) - groundnut (Jan.-April) – gingelly (April-June)
Rice (Aug.-Jan.) -pulses/sesame/cotton (Jan.-April)
Sugarcane - ratoon sugarcane (Dec.-Nov.) - (2 years rotation)
Rice (Aug.-Jan.) – cotton +onion /gingelly (Feb-May)

Normal year

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly(Feb.-May)
Maize (Pulses) / vegetables (June-Sep.) - rice (Oct-Jan.) – pulses/cotton + onion / gingelly/ sunflower (Feb.-May)
Sugarcane - ratoon sugarcane (Dec.-Nov.) - (2 years rotation)
Rice (Aug.-Jan.) - cotton + onion /gingelly (Feb-May)

Moderate drought year

Maize/vegetables/pulses/sesame/green manure (June-Sep.) - rice (Aug.-Jan.) - pulses / senna* (Feb.-May)
Coleus* / *Periwinkle**/ senna* (June-Nov.)

Severe drought year

Pulses (June-Sep.) - sunflower/coriander/cotton (Oct.-Feb.) - fallow
Millets / green manure / gingelly (June-Sep.) -maize/ fodder (Oct.-Feb.) - pulses (Feb.-May)

b. Well irrigated areas: red, black and laterite soils

Existing

Sugarcane - ratoon sugarcane (Nov.-Dec.) - (2 years rotation)
Rice (Aug.-Jan.) - groundnut (Jan.-April)
Rice (Oct.-Jan.) – gingelly (Feb.-May)
Vegetables (June-Sep.) - rice (Oct.-Feb.)
Banana (Jan.-Dec.) - ratoon banana (Jan.-Dec.) - rice (Dec.-April)

Normal year

Banana (June-May) - ratoon banana (May-June) (Drip-Fertigation)
Vegetables (June-Sep.) - rice (Oct.-Jan.)
Pulses / gingelly (Feb.-April)
Vegetables / onion (June-Sep.) - rice (Oct.-Jan.) - maize / pulses / gingelly (Feb.-May)
Gloriosa (2 years rotation)
Coleus* (June-Oct.) - rice (Nov.-Feb.) - pulses / gingelly (June-Oct.)
Flower crops (June planting)
Sugarcane - ratoon sugarcane (Nov.-Dec.) - (2 years rotation)

Moderate drought year

Maize (Aug.-Dec.) - gingelly/ soybean / sunflower (Dec.-March)
Fodder / pulses / green manure (Aug.-Dec.) -sesame/groundnut / sunflower / sorghum / pearl millet (Dec.-March)
Cotton (Aug.-Feb.) – fallow

Severe drought year

Clusterbean / lab lab / bhendi (July-Dec.) -water melon / cluster bean / cucumber (Jan.-April)
*Periwinkle**/ senna* (June-Sep.)

c. Rainfed areas: black, laterite and red soils

Existing

Gingelly (July-Oct.)- cotton + coriander (Nov.-Feb.)
Gingelly(July-Oct.) - horsegram (Nov.-Feb.)
Pearl millet / sorghum / maize (July-Oct.) - coriander / groundnut (Nov.-Feb.)

Normal year

Gingelly (July-Oct.) - cotton + coriander (Nov.-Feb.)
Gingelly (July-Oct.) - horsegram (Nov.-Feb.)
Pearl millet / sorghum / maize (July-Oct.) - coriander / groundnut (Nov.-Feb.)

Moderate drought year

Cotton (Aug.-Feb.) - fallow
Gingelly (July-Oct.) - horsegram (Oct.-Feb.)

Severe drought year

Fodder sorghum / minor millets / fodder / coriander (Oct.-Feb.)

6. Pudukottai district

Mean annual rainfall (mm) -917.4
Cold weather period (Jan.-Feb) -33.2
Summer (March-May) -115.5
South West monsoon season (June-Sept) -350.7
North East monsoon season (Oct.-Dec.) -418.0

a. Command areas: alluvial and laterite soils

Existing

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)
Rice (Aug.-Jan.) - pulses / gingelly/ cotton (Jan.-April)
Sugarcane (Jan.-Dec.) - ratoon sugarcane (Nov.-Dec.) – 2 years rotation
Direct sown rice (Aug.-Jan.) - groundnut (Jan.-April)
Rice (Aug.-Jan.) – gingelly (Jan.-April)
Rice (Aug.-Jan.) - pulses / groundnut / gingelly (Jan.-April)
Rice (Aug.-Jan.) - groundnut (Jan.-April) – gingelly (April-June)

Normal year

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)
Rice (Aug.-Jan.) - pulses/sesame/cotton (Jan-Apr)
Sugarcane - ratoon sugarcane (Nov.-Dec.)
Director sown rice (Aug-Jan)-groundnut (Jan-Apr)
Rice (Aug.-Jan.) - gingelly (Jan.-April)
Rice (Aug.-Jan.) - pulses / groundnut / gingelly (Jan.-April)
Rice (Aug.-Jan.) - groundnut (Jan.-April) – gingelly (April-June)

Moderate drought year

Direct sown short duration rice - (Sep.-Dec.)
Groundnut / gingelly (Dec.-March)
Coleus* (June-Nov.) - pulses (Dec.-Feb.)
Maize / clusterbean / lab lab / bhendi / pulses / sesame/green manure (June-Sep) - rice (Aug-Jan.) -pulses (Feb.-May)

Severe drought year

Pulses (June-Sep.) - groundnut /gingelly (Sep.-Dec.)
Millets / green manure / gingelly (June-Sep.) -maize / fodder / pulses (Oct.-Feb.)
*Periwinkle**/ senna* (Oct.-Jan.)

b) Tankfed areas: laterite and red soils

Existing

Rice (Aug.-Jan.) - pulses (Feb.-April)
Rice (June-Sep.) - ragi (Sep.-Dec.) - pulses (Jan.-April)
Rice (July-Nov.) - ragi/groundnut (Dec.-March) - fallow
Ragi (April - July) - rice (July-Nov.) - groundnut/pulses (Dec.-Feb.)

Normal year

Rice (Aug.-Jan.) - pulses (Feb.-April)
Ragi (April - July) - rice (July-Nov.) - groundnut
Clusterbean / lab lab / bhendi (June-Sep.) - rice (Oct.-Jan.) - fallow

Severe drought year

Fodder maize/ fodder cowpea / water melon / cucumber (Oct.-Feb.)

c. Well irrigated areas: laterite, red and sandy soils

Existing

Groundnut (April-July) - rice (Aug.-Jan.) - pulses (Feb.-April)
Ragi (April-July) - rice (Aug.-Jan.) - pulses (Feb.-April)
Sugarcane - ratoon sugarcane (Nov. -Dec.) - (2 years rotation)
Ragi (April-July) - maize (Aug.-Jan.) - pulses (Feb-April)
Banana - ratoon banana (July-May) - (2 years rotation)

Normal year

Groundnut (April-July) - rice (Aug.-Jan.)- pulses (Feb.-April)
Ragi (Apr-July)- rice (Aug.-Jan.)-pulses (Feb.-Apr)
Sugarcane - ratoon sugarcane (Nov.-Dec.) - (2 years rotation)
Ragi (April-July) - maize (Aug.-Jan.) - pulses (Feb-April)
Banana - ratoon banana (July-May) - (2 years rotation)

Moderate drought year

Ragi (April-July) - maize (Aug.-Jan.) - pulses (Feb.-April)
Watermelon (Dec.-March) - groundnut (April-July) – fallow

Severe drought year

Fodder sorghum / fodder maize / fodder cowpea / green manure (Oct.-Feb.)

d. Rainfed areas: laterite and red soils

Existing

Groundnut + redgram (June-Jan.)
Groundnut + castor (June-Jan.)
Varagu + pearl millet (Aug.-Jan.)
Groundnut (June-Sep.) - ragi (Sep.-Jan.)
Ragi + castor (June-Jan.)

Normal year

Groundnut + redgram (June-Jan.)
Groundnut + castor (June-Jan.)
Varagu + pearl millet (Aug.-Jan.)
Groundnut (June-Sep.) - ragi (Sep.-Jan.)
Ragi + castor (June-Jan.)

Moderate drought year

Pulses (June-Sep.) - ragi (Oct.-Feb.)
Ragi + castor (June-Jan.)

Severe drought year

Fodder sorghum / fodder cowpea/castor / cucurbits (June-Jan.)

7. Cuddalore district: (Chidambaram and Kattumannarkovil)

Mean annual rainfall (mm) -1248.1
Cold weather period (Jan.-Feb) -65.6
Summer (March-May) -92.4
South West monsoon season (June-Sept) -373.6
North East monsoon season (Oct.-Dec.) -716.5

a. Command areas: heavy clay soils

Existing

Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)
Rice (Aug.-Jan.)- pulses/sesame/cotton (Jan.-Apr)
Sugarcane - ratoon sugarcane (Dec.-Nov.) - rice (Dec.-May) – groundnut (June-Sep./Oct.) - (three years rotation)

Normal year

Rice (June - Sep.) - rice (Oct.-Jan.) - pulses / gingelly (Feb.-May)

Rice (Aug.-Jan.)- pulses/sesame/cotton (Jan.-April)

Maize / vegetables / pulses / gingelly / green manure (June-Sep.) – rice (Aug.-Feb.) - pulses (Feb.-May)

Sugarcane - ratoon sugarcane (Dec.-Nov.) - rice (Dec.-May) – groundnut (June-Sep./Oct.) - (three years rotation)

Moderate drought year

Maize / clusterbean / lab lab / bhendi / gingelly / green manure (June-Sep.) - rice (Aug.-Feb.) – gingelly (Feb.-May)

Severe drought year

Millets / green manure / season (June-Sep.) -maize / fodder (Oct.-Feb.) – gingelly (Feb.-May)

Perennial trees : 20% of cultivable area sapota, amla, cashew, bamboo, mango, casuarina

Inland fisheries and dairy

Biofuel crops are recommended only with industrial tie-up

Medicinal plants are recommended only with buy back arrangement

Contingent/Alternate crop plans for normal water supply

If canal irrigation water availability is normal or near normal and even if the time of release of water is delayed by one or two fortnights, the normal cropping pattern of Kuruvai-Thaladi or Samba followed by pulses, cotton or vegetables can be adopted in Cauvery and Vennar Systems. In the G.A. canal area, the single cropped samba rice with medium duration varieties in August to December season followed by groundnut in December to March season and pulses, gingelly or maize in April to July can be raised. Adoption of this normal cropping pattern assumes that there is the adequate South-West Monsoon rains in the catchment areas of Cauvery and thereby good storage position in the Mettur Dam.

Contingent/Alternate crop plans when Canal water is not available

If adequate canal water is not available for raising kuruvai paddy, then a plan solely dependent on the rainfall has to be drawn. About 40-50 mm of rainfall is normally received during May and using this rain, summer ploughing has to be done on a large scale in the delta. This operation not only conserves moisture and checks weed growth but also makes dry sowing easy. During the months of June – July, an average rainfall of about 100 mm is received. Using these rains, short duration pulses like green gram and black gram and millets like bajra and finger millet can be raised as dry crops in clayey soils in Cauvery and Vennar basins. Gingelly can be grown in loamy soils and groundnut in light soils. In the G.A. canal area, pulses and gingelly can be raised in this season. In August, another 80 – 100 mm rains is received and this is sufficient to support the dry crops. If the Storage position improves in the Mettur reservoir late in the season, one or two wettings can be given to these crops which will push up the yields considerably. But on no account, water should be let in the canal for rice cultivation after the above said dry crops are raised except for the occasional wettings. In these assured irrigated area, Kuruvai rice crop can be planted in June and harvested in September well before the onset of North-East monsoon.

In the entire delta, except filter point and bore well irrigated areas, a single crop (Samba) as rainfed rice can be raised in August to December months. Using the August rains, the fields can be prepared after the harvest of dry crops and rice can be dry seeded using a high seed rate 75-100 kg /ha. In heavy soils, furrows at an interval of 2 to 3 m can be formed to drain excess water. Appropriate weed management techniques with the application of suitable herbicides may be followed to control weeds. The initial rains in August and September are sufficient for germination and establishment. After the onset of North-East monsoon rains and receipt of canal water (whichever is earlier), the fields can be converted into wetlands and water can be impounded. In well irrigated areas, Thaladi rice can be raised after kuruvai crop.

In Samba areas of Cauvery and Vennar basins, using the residual moisture, short duration pulses can be relay sown during the period between 15th January to 15th February. In G.A. canal area, groundnut can be raised with supplemental splash irrigation. In filter point irrigated areas, cotton, vegetables or gingelly can be raised in summer. Alternately, one rice fallow pulses after Thaladi and another summer pulse in April to June with irrigation can be raised. In G.A. Canal area, maize, gingelly or pulses can be raised after the groundnut crop in areas with irrigation facilities.

CROP INTENSIFICATION AND CROP SUBSTITUTION IN THE DISTRICTS OF TAMIL NADU

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The State Tamil Nadu is geographically located between 8°5′ and 13°35′ North latitude and between 76°14' and 80°21′ East longitude. As a result of this geographical position, Tamil Nadu enjoys semi arid climate, which permits higher crops productivity under irrigation. Out of 13 million hectares of geographical area, which is 3.95 per cent of total geographical area of India, the cultivable area in Tamil Nadu is around 7 million hectares and 55 per cent of which is dryland. Agro-climatically Tamil Nadu has been divided into seven zones.

Monsoon rainfall is the basic resource for water availability in Tamil Nadu. The dominant monsoon for rainfall is north-east monsoon (Oct.-Dec.) which contributes about 42 to 48 per cent to total annual rainfall of each district of Tamil Nadu. Nevertheless the contribution from south-west monsoon (June-Sep.) to Tamil Nadu is around 32 per cent and it benefits Dharmapuri, Salem, Namakkal, Kanyakumari, The Nilgiris, Vellore and parts of Villupuram, Cuddalore,Karur, Thiruvallur and Perambalur districts.

If any negative deviation from normal rainfall occurs in Tamil Nadu either during north east monsoon season or during south west monsoon season, in a year, the water availability in Tamil Nadu would affect three major water sources of irrigation viz., canals, wells and tanks. The normal rainfall in Tamil Nadu is 46.4, 140.9, 334.0 and 459 mm respectively for cold weather period (Jan.-Feb.) hot weather period (March-May), south- west monsoon period (June-Sep.) and north east monsoon period (Oct.-Dec.).

Sometimes continuous meteorological drought occurred in both the monsoons that led to agricultural drought in Tamil Nadu. This situation has driven to think on the development of alternate crops to Tamil Nadu. In the past, because of the sound soil health, limited human population, and unlimited water availability, farmers have their own set of cropping pattern in command areas, tankfed areas, well-irrigated areas and dryland areas. Because of changing rainfall pattern over years due to deforestation, urbanization, over population etc., groundwater depletion is triggered to be faster. Considering them it is time to reduce the area under rice by 20 per cent and for sugarcane by 40 per cent to accommodate other demanding crops like oilseeds, pulses, cotton, maize etc., The aim of substituting rice and sugarcane by other crops is not only because of shrinking water resource, but also due to the fact that surplus in rice and sugarcane production achieved in the State of Tamil Nadu. Hence, it is imperative to design alternate cropping system based on soil and climatic resources in addition to social requirements of Tamil Nadu.

I. North Eastern Zone

1. Kancheepuram district

Tank irrigated:

- Rice (Aug.-Jan.) - rice / maize (Jan.-April)

Well irrigated:

- Rice/vegetables/marigold(June-Oct.) - maize(Oct.-Jan.) - pulses (Feb.-May)
- Rice (Aug.-Jan.) - groundnut (Feb.-April) - Sesame
- Sugarcane (Dec.-Jan.) - ratoon sugarcane (Jan.-Nov.) – rice (Dec.-May) - groundnut(June- Sep./Oct.) - 3 years rotation

Rainfed areas:

- Maize (June-Sep.) - groundnut (Oct.-Feb.)
- Rice (July-Nov.)

2. Thiruvallur district

Tank irrigated:

- Rice/Vegetables/watermelon (Aug.-Jan.)- groundnut/Sesame / pulses (Feb.-May)

Well irrigated:

- Rice (April-Aug.) – groundnut (Sep.-Dec.) - vegetables / sesame (Jan.-March)
- Vegetables (June-Oct.) - maize (Oct.-Jan.) – pulses (Feb.-May)

Rainfed areas:

- Dry rice (June-Aug.)-maize/Vegetable/ groundnut / pulses (Sept.-Jan.)
- Groundnut (June-Sep.) - pulses/ Sesame (Oct.-Feb.)

3. Villupuram district

Canal irrigated:

- Rice (Aug.-Jan) – pulses/sesame/maize (Jan.-April)

Tank irrigated:

- Rice (Aug.-Jan.) – pulses (including moth bean (Jan.-Apr.)

Well irrigated:

- Sugarcane (Dec.-Jan.) – ratoon sugarcane (Jan.-Nov.) - rice (Dec.-May) - groundnut (June - Sep./Oct.) – 3 years rotation
- Rice (Aug.-Jan.) - groundnut (Feb.-April) – sesame (April - June)
- Maize (June-Sep) – marigold (Oct.-Feb.)- pulses (Feb.-May)

Rainfed areas:

- Maize /pearl millet (June-Sep.) - groundnut (Oct-Feb)

4. Thiruvannamalai district

Canal irrigated:

- Rice/maize (Aug.-Jan.) - pulses/sesame (Jan.-Apr.)

Well irrigated:

- Rice (Aug.-Jan.) – groundnut (Feb.-April) – sesame (Apr. - June)
- Sugarcane (Dec.-Jan.) - ratoon sugarcane (Jan.-Nov.) - rice (Dec.-May) - groundnut (June- Sep.) – 3 years rotation
- Vegetables (June-Oct.) - maize (Oct.-Jan.) - cotton / pulses (Feb.- May)

Rainfed areas:

- Groundnut / maize (June-Sep.); Groundnut / pulses / finger millet (Oct.-Feb.)

5. Vellore district

Tank irrigated :

- Rice/vegetables (Aug.-Jan.) - sesame/ pulses (Feb.- May)

Well irrigated:

- Sugarcane (Dec.-Jan.) – ratoon sugarcane (Jan.-Nov.)- rice (Dec.-May) - groundnut (June- Sep./Oct.) - 3 years rotation
- Rice (Aug.-Jan.) - groundnut (Feb.-April) - sesame/ pulses/ maize (April - June)
- Vegetables (June-Oct.) - maize (Oct.-Jan.) – pulses (Feb.-May)

Rainfed areas:

- Pearl millet/sorghum(June-Sep.) - groundnut (Oct-Feb.) Maize (June-Sep.) - groundnut (Oct.-Feb.)

6. Cuddalore district

Canal irrigated:

- Rice (Aug.-Jan.) - pulses/sesame/cotton (Jan.-April)
- Maize /vegetables/pulses/sesame/ green manure (June-Sep.) - rice (Aug.-Feb.) - pulses (Feb.-May)
- Sugarcane (Dec.-Nov.) - ratoon sugarcane (Dec.-Nov.) - rice (Dec.-May) - groundnut (June- Sep./Oct.) - 3 years rotation

Tank irrigated:

- Rice/vegetables (Aug.-Jan.) - Sesame/ pulses (Feb.-May)

Well irrigated:

- Rice (Aug.-Jan.) – groundnut (Feb.-April) – Sesame(April - June)
- Maize (June-Sep.) – marigold (Oct.-Feb.) - pulses(Feb.-May)
- Vegetables (June-Oct.) - maize (Oct.-Jan.) - pulses(Feb.-May)

Rainfed areas:

- Maize/pearl millet (Jun.-Sep)- groundnut (Oct-Feb)
- Groundnut (June-Sep.) - pulses / Sesame (Oct.-Jan.)

II. North Western Zone

1. Dharmapuri district

Canal irrigated:

- Cotton (Aug.-Jan.) - greengram/cowpea(Feb.-April)
- Bhendi / cluster bean / water melon (June-Sep.) -rice / Finger millet (Dec.-March)

Well irrigated:

- Tapioca (Jan.-Dec.)
- Groundnut (June-Sep.) - wheat / cole vegetables(Oct.-Feb.) - pulses / sesame (Feb.-May)
- Cotton (Aug.-Feb.) - pulses / sesame (Feb.-May)

Rainfed areas:

- Tapioca (May-Jan.)
- Finger millet / groundnut / sunflower / castor / sorghum/
- Pigeon pea + Garden bean/ finger millet / little millet / barnyard millet (May-Oct.) - Minor pulses (Nov.- Jan.)

2. Salem district

Canal irrigated:

- Rice (Aug.-Nov.) - cotton (Dec.-May)/ sesame/ groundnut (Dec.- Mar.)
- Cotton (Aug.-Jan.)- greengram/ cowpea(Feb.-Apr)
- Bhendi / cluster bean / water melon (June-Oct.) -rice (Dec.- March)

Well irrigated:

- Tapioca (Nov.-Oct.) - short time fallow
- Rice (Aug.-Jan.) - cotton (Feb.- June) / sesame(Feb.-May) / groundnut (Feb.-May)
- Cotton (Aug.-Jan.) - pulses / groundnut(Feb.-April)

Rainfed areas:

- Tapioca (June-Feb.)
- Groundnut + pulses (May-Sep.) - sorghum + pulses(Oct.-Feb.)
- Sorghum / finger millet / maize / pearl millet (May-Sep.) -pulses (Oct.-Jan.)
- Castor (May-Sep.) - pulses (Oct.- Jan.)

3. Namakkal District

Canal irrigated:

- Bhendi / cluster bean / watermelon (June-Sep.) -rice (Dec.- March)
- Cotton (Aug.-Jan.) - greengram / cowpea(Feb.-April)
- Rice (June-Sep.) - rice (Oct.-Feb.)

Well irrigated:

- Tapioca (Jan.-Dec.)
- Cotton (Aug.-Jan.) - pulses (Feb.- April)
- Rice (Sep.-Jan.) - cotton (Feb.- June)
- Turmeric (May-Jan.)
- Groundnut (Apr-Jul)-maize(Aug- Nov.)-finger millet (Dec-Mar)

Rainfed areas:

- Tapioca (June-May)
- Groundnut + castor / pulses (May- Jan.)

III. Western Zone

1. Erode district

Canal irrigated:

- Rice (Aug.-Jan.) - Sesame/groundnut (Feb.-April)
- Sugarcane (Dec.-Nov.) - ratoon sugarcane (Dec.-Nov.) (2 years rotation)
- Turmeric (May-Jan.) - rice (Feb.- April)
- Groundnut (June-Sep.) - rice (Oct.-Jan.) - maize(Feb.-May)

Well irrigated:

- Sugarcane (March-Jan.) – ratoon sugarcane (Feb.-Dec.) - millets / cotton (Jan.-April) / (Jan.-May)
- Cotton (Aug.-Dec) - coleus* / vegetables (Jan.-July)
- Turmeric (May-Dec.) - maize / hybrid tomato /capsicum / green chillies (Jan.-April)

Rainfed areas:

- Maize / sorghum (June-Sep.) - pulses (Oct.-Jan.)
- Cotton (Sep.-Feb.) - fallow

2. Coimbatore district

Canal irrigated:

- Rice (Aug.-Jan.) - sesame/groundnut (Feb.-April)
- Sugarcane (Dec.-Nov.) - ratoon sugarcane (Dec.-Nov.) (2 years rotation)
- Turmeric (May-Jan.) - rice (Feb.- April)
- Groundnut (June-Sep.) - rice (Oct.-Jan.) - maize(Feb.-May)

Well irrigated:

- Cotton (Aug.-Feb.) - sorghum (March - June)
- Turmeric (May-Dec.) - groundnut (Dec.-March)
- Rice (Aug.-Jan.) - finger millet (Feb.-June) - pulses(June-Aug.)

Rainfed areas:

- Maize / millets (July-Sept.) - pulses (Sep.-Dec.)
- Cotton (July-Nov.) - wheat (Nov.- Feb.)
- Maize (July-Oct.) – chick pea / coriander (Nov.-Feb.)

Karur district

Canal irrigated:

- Turmeric (May-Dec.) - rice (Jan.- April)
- Rice (Aug.-Dec.) - groundnut (Dec.-March)
- Rice (Aug.-Jan.) – sesame / pulses / cotton / sorghum(Feb.- May)
- Sugarcane (Dec.-Nov.) - ratoon sugarcane (Dec.-Nov.) - rice (Dec.-March)
- Banana (June-March) - ratoon banana (April-Jan.) – 2 years rotation

Well irrigated:

- Sugarcane (March-Jan.) – ratoon sugarcane (Feb.-Dec.) - millets/ cotton (Jan.-April) - (2 and half years rotation)
- Cotton (Aug.-Dec.) - millet / vegetables(Jan.-April) - Groundnut (May-July)
- Turmeric (May-Dec.) - sesame/ sorghum / maize(Jan.-April)
- Rice (Aug-Dec)-sesame/ groundnut/pulses (Jan-Apr)

Rainfed areas:

- Maize / millets (July-Aug.) - pulses (Oct.-Jan.)
- Cotton (July-Nov.) - wheat (Nov.- Feb.)

4. Dindigul district

Canal irrigated:

- Rice (Oct.-Jan.) - vegetables / groundnut/ Sesame (Feb.-May)
- Sugarcane (Dec.-Nov.) - single crop
- Banana (June-March) - ratoon banana (April-Jan.) – 2 years rotation

Well irrigated:

- Sugarcane (Feb.-Dec.) – single crop
- Cotton (Aug.-Dec.) - millets / vegetables(Jan.-April) - groundnut (May-July)
- Rice (Aug.-Jan.) - vegetables / millet / groundnut /pulses (Jan.- April)

Rainfed areas:

- Groundnut + pulses / maize / millets / pulses (July-Oct.) - pulses (Oct.-Jan.)

5. Theni district

Canal irrigated:

- Rice (June-Sep.) - rice (Oct.-Jan.) - green manure / pulses (Feb.- April)

Well irrigated:

- Sugarcane (March-Jan.) – ratoon sugarcane (Feb.-Dec.) - green manure (Jan.-Feb.) – 2 years rotation
- Cotton (Aug.-Jan.) - millets / vegetables / groundnut (Feb.- June)
- Maize (Aug.-Nov.) - sorghum / pearl millet(Dec.-Feb.) - vegetables (March-July)
- Rice (Aug.-Jan.) - vegetables / pulses / groundnut(Jan.-March)

Rainfed areas:

- Millets / maize / groundnut / pulses (June-Oct.) -Minor pulses/ pulses (Nov.-Feb.)

IV. Cauvery Delta Zone

1. Thanjavur district

Canal irrigated:

- Maize / pulses / vegetables (June- Sep.) - rice (Oct.- Jan.) - pulses / cotton / sesame/ sunflower (Feb.- May)
- Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / sesame (Feb.-May)

Well irrigated:

- Banana (June-May) – ratoon banana (May-June) - (drip- Fertigation) - 2 years rotation
- Vegetables (June-Sep.) - rice (Oct.-Jan.) – pulses (Feb.-April)
- Vegetables / onion (June-Sep.) - rice (Oct.-Jan.) -maize / pulses (Feb.-May)

2. Thiruvarur district

Canal irrigated:

- Sugarcane - ratoon sugarcane (Feb.-Dec.)
- Rice (June-Sep.) - rice (Oct.-Jan.) - pulses /sesame(Feb.-May)

Well irrigated:

- Pulses/groundnut/sesame (June- Sep.) - rice(Oct.-Feb.) - groundnut / green gram/ pulses(Feb.-May)
- Rice (Aug.-Dec.) – groundnut (Dec.-Mar.)

3. Nagapattinam district

Canal irrigated:

- Sugarcane - ratoon sugarcane (Feb.-Dec.)
- Rice (June-Sep.) - rice (Oct.-Jan.) -pulses /sesame(Feb.-May)

Well irrigated:

- Rice/pulses/groundnut/Sesame (June-Sep.) - rice(Oct.-Feb.) - groundnut / green gram/ pulses(Feb.-May)

4. Trichirapalli district

Canal irrigated:

- Maize/pulses/vegetables (June- Sep.) - rice(Oct.-Jan.) - pulses / cotton / sesame/ sunflower(Feb.- May)
- Sugarcane - ratoon sugarcane (Dec.-Nov.) - (2 years rotation)
- Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / Sesame (Feb.-May)

Well irrigated:

- Banana (June-May) – ratoon banana (May-June) (Drip- Fertigation)
- Vegetables (June-Sep.) - rice (Oct.-Jan.) – pulses (Feb.-April)
- Rainfed areas: Groundnut + pigeon pea (Oct.- Feb.)

5. Perambalur district

Canal irrigated:

- Rice (June-Sep.) - rice (Oct.-Jan.) - pulses /sesame(Feb.-May)
- Maize (Pulses) / vegetables (June-Sep.) - rice (Oct.-Jan.) - pulses/cotton + onion / sesame/ sunflower(Feb.-May)
- Sugarcane - ratoon sugarcane (Dec.-Nov.) - (2 years rotation)

Well irrigated:

- Banana (June-May) – ratoon banana (May-June) (Drip- Fertigation)
- Vegetables / onion (June-Sep.) - rice (Oct.-Jan.) - maize / pulses / sesame (Feb.-May)

Rainfed areas:

- Sesame (July-Oct.) - cotton + coriander(Nov.-Feb.)

6. Pudukottai district

Canal irrigated:

- Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / sesame(Feb.-May)
- Rice (Aug.-Jan.) - pulses/sesame/ cotton (Jan-Apr)
- Sugarcane - ratoon sugarcane (Nov.-Dec.)

Tank irrigated:

- Rice (Aug.-Jan.) - pulses (Feb.- April)
- Rice (June-Sep.)-finger millet (Sep-Dec.)-pulses (Jan.-Apr)

Well irrigated:

- Groundnut (April-July) – rice (Aug.-Jan.)- pulses(Feb.-April)
- Finger millet (Apr-July)- rice (Aug.-Jan.)-pulses (Feb.-Apr)
- Sugarcane - ratoon sugarcane (Nov.-Dec.) - (2 years rotation)
- Banana - ratoon banana (July- May) - (2 years rotation)

Rainfed areas:

- Groundnut + pigeon pea (June- Jan.)

V. Southern Zone

1. Madurai district

Canal irrigated:

- Rice (June-Sep.) - rice (Oct.-Jan.) – pulses (Feb.-April)
- Sugarcane - ratoon sugarcane (Nov.-Dec.) - (2 years rotation)

Tank irrigated:

- Rice (Sep.-Jan.) - cotton (Feb.- Aug.)

Well irrigated:

- Vegetables /groundnut (July-Jan.) - cotton (Feb.-Jun)
- Rice (Oct.-Jan.) - pulses (Feb.- April)

Rainfed areas:

- Cotton + pulses (Sep.-Feb.)
- Maize / pulses / coriander / sunflower (Jan.-April)

2. Ramanathapuram district

Canal irrigated:

- Rice (Sep.-Jan.) - cotton (Jan.- Feb.)

Tank irrigated:

- Rice (Sep.-Jan.) - cotton (Feb.- Aug.)

Well irrigated:

- Rice (Sep.-Jan.) - cotton (Feb.- Aug.)
- Rice (Sep.-Jan.) - groundnut (Feb.-May)
- Groundnut (June-Sep.) - chillies (Oct.-Feb.)

Rainfed areas:

- Upland rice/millets / pulses / groundnut / cotton / chillies (Sep.- Feb.)

3. Virudhunagar district

Tank irrigated:

- Rice (Sep.-Jan.) - cotton (Feb.- Aug.)
- Well irrigated: Chillies / groundnut (July-Jan.)- cotton (Feb.-June)
- Pearl millet (June-Aug.) - chillies (Oct.-April)

Rainfed areas:

- Cotton + blackgram / chillies (Sep.-Feb.)
- Sorghum / maize/groundnut / sunflower /sesame(Sep.-Jan.)

4. Sivagangai district

Canal irrigated:

- Rice (Sep.-Jan.) - cotton / pulses/ millets / vegetables / sesame (Feb.-Aug.)

Well irrigated:

- Groundnut / pulses / vegetables (June-Sep.) – rice (Oct.-Feb.)
- Sugarcane - ratoon sugarcane (Nov.-Dec.) – 2 years rotation
- Banana (July-June) - ratoon banana (June-March) - (2 years rotation)

Rainfed areas:

- Groundnut + pulses (June-Sep.)- sesame(Oct.-Jan.)

5. Tirunelveli district

Canal irrigated:

- Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / sesame(Feb.-April)

Tank irrigated:

- Rice (Sep.-Dec.) - pulses (Jan.- April)

Well irrigated:

- Chillies / groundnut / rice (July- Jan.) - cotton (Feb.-June)
- Rice (Oct.-Feb.) - pulses (March - July)

Rainfed areas:

- Cotton + blackgram / chillies (Sep.-Feb.)
- Maize / millets / groundnut / sunflower (Sep.-Feb.)

6. Thoothukudi district

Canal irrigated:

- Rice (June-Sep.) - rice (Oct.-Jan.) - pulses / sesame (Feb.-April)

Tank irrigated:

- Rice (Sep.-Jan.) - cotton (Feb.- Aug.)
- Maize / rice (June-Sep.) - chillies (Oct.-Feb.)

Well irrigated:

- Chillies / groundnut (July-Jan.) - cotton (Feb.-June)
- Rice (Oct.-Feb.) - pulses (March - July)

Rainfed areas:

- Cotton + blackgram / chillies (Sep.-Feb.)
- Maize / millets / groundnut / sunflower (Sep.-Feb.)

VI. High Rainfall Zone - Kanyakumari District

Canal irrigated:

- Rice (April-Aug.) - rice (Sep.- March) - fallow
- Banana - ratoon banana (April - Jan.) - (2 years rotation)

Tank irrigated:

- Rice / maize (June-Oct.) – rice (Oct.-Feb.) – pulses (Feb.-May)

Well irrigated:

- Tapioca + pulses (Sep.-July)
- Red banana (June-May)
- Rice (Oct.-Feb.) - pulses (Feb.- May)

Rainfed areas:

- Tapioca + pulses (April-Dec.)

VII. Hilly and High Altitude Zone

Nilgris

- Tea and coffee
- Rosemary and thyme, potato, cabbage, radish and carrot (grow these crops in terrace)
- Cut flowers

Kodaikanal

- Lower Palani hills – Coffee, Mandarin, Cocoa, Vanilla, Chowchow,
- Pineapple, French beans, Avocado, Cardamom, Pepper and Cut flowers.
- Upper Palani hills – Potato, Pear, Peaches, Plums, Apple Garlic, Cabbage, Ginger

PROCESSING AND VALUE ADDITION OF PRODUCTS AS VERTICAL APPROACH FOR CROP DIVERSIFICATION

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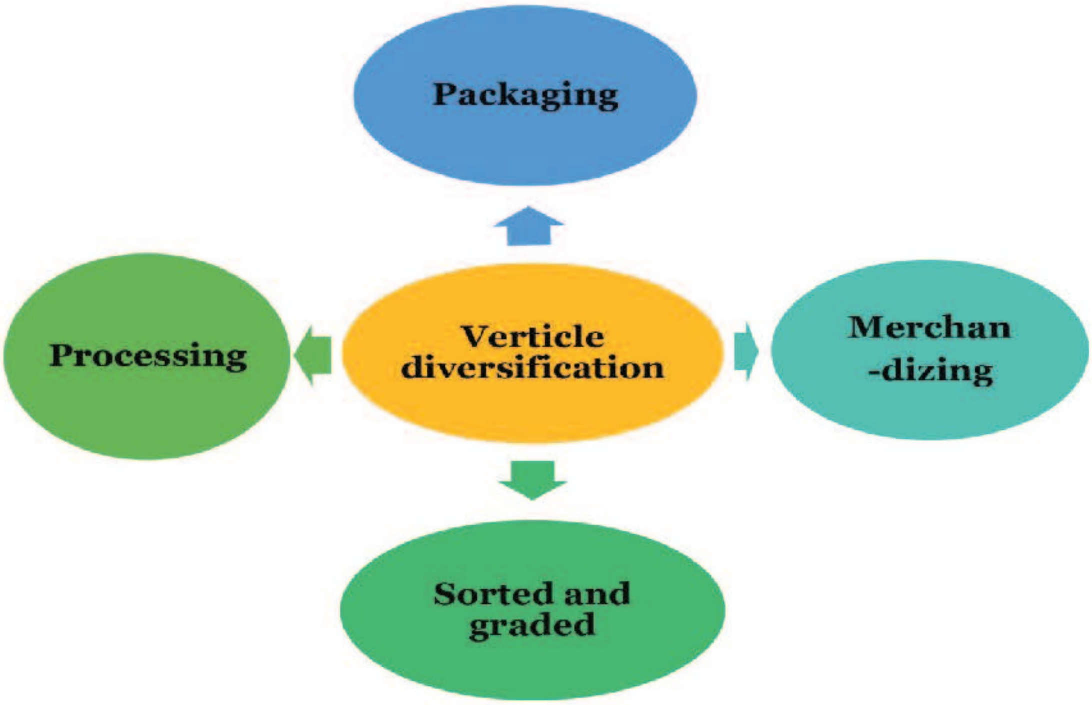
Vertical diversification

Vertical crop diversification, on the other hand, represents the degree and level of industrialization of agricultural production. In this approach famers and others add value to products through packaging, processing, regional branding, merchandizing to improve the marketable value of crops. Food crop vertical diversification is also described as the extension of post-harvest activities, such as processing and transformation industries, to allow food crops to be sorted, graded, processed into both food and industrial products, packed, stored, and transported to domestic or export markets. The rise of processing and transformation industries appears to be the most important factor in rural areas in terms of creating revenue and jobs. To boost crop yields and income creation at the local, regional, and national levels, both types of diversification (i.e., multiple cropping or horizontal diversification and agri-business or vertical diversification) will be required.



Options of vertical diversification

Processing and Value addition of millets

Millets are considered as crop of food security because of their sustainability in adverse agro-climatic conditions. These crops have substantive potential in broadening the genetic diversity in the food basket and ensuring improved food and nutrition security. Along with nutrition millets offer health benefits in daily diet and help in the management of disorders like diabetes mellitus, obesity, hyperlipidemia, etc. Millets offer unique advantage for health being rich in micronutrients, particularly minerals and B vitamins as well as nutraceuticals. Though millets are not the important part of daily diet of American and European people, now these countries have recognized the importance of millets as ingredient in multigrain and gluten-free cereal products. However, in many Asian and African countries millet is the staple food of the people in millet producing areas and used to prepare various traditional foods and beverages like idli, dosa, papad, chakli, porridges, breads, infant and snack foods. Whilst a number of traditional foods are made in the domestic household, the lack of large-scale industrial utilization discourages the farmers raising millet crops. Therefore, many countries Including India, China, USA etc. have now started research projects to study and develop process technology for nutritional improvement and harvest health benefits and promote their utilization as food on large scale. 21st century challenges like climate changes, water scarcity, increasing world population, rising food prices, and other socioeconomic impacts are expected to generate a great threat to agriculture and food security worldwide, especially for the poorest people who live in arid and sub-arid regions. Typical grain texture and hard seed coat of millets increases their keeping quality but makes them difficult to process as well as cook in convenient form. Absence of appropriate primary processing technologies to prepare ready-to-use or ready-to-cook (RTC) products and also secondary as well as tertiary processing to prepare ready-to-eat value added products have been the major limiting factors for their diversified food uses and better economic status.

Millets have relatively poor digestibility and low bio-availability of minerals due to presence of inherent anti-nutritional factors. An increasingly important determinant in food choice is the growing consumer concern about nutrition and health. The difficulties in millet grain processing present a challenge but nutritional as well as health benefits and consumer demand for health foods provide opportunities in processing, development of suitable technology for newer products and process mechanization. This change in technology and consumer food preference would help in increasing the area under millets, maintaining ecological balance, ensuring food security, prevent malnutrition and increase the scope for utilization of millet grains on industrial scale. Different studies on processing of millets have yielded promising results in their successful utilization for various traditional as well as convenience health foods. Accordingly different researchers have tried to develop processed products like popped, flaked, puffed, extruded and roller dried products; fermented, malted and composite flours; weaning foods, etc. For example, exploratory studies on popping and milling of millets have been promising. Extrusion of weaning foods of pearl millet increases the protein digestibility whereas germination and probiotic fermentation causes significant improvement in protein profile and in-vitro mineral availability.

Processing and Value addition of Pulses

Pulses are an important commodity group of crops that provide high quality protein complementing cereal proteins for pre-dominantly substantial vegetarian population of the country. Legumes like pea, lentil, soybean, mungbean, cowpea, pigeon pea, beans, chickpea etc. supply macro as well as micronutrients, carbohydrates (including dietary fibres) as well as vitamins and minerals. In addition, they also contain bioactive phytochemicals that possess antioxidant activity. Antioxidants are the compounds which scavenge free radicals like reactive oxygen species and reactive nitrogen species, thus reduce or inhibit the cellular damage caused by them. Extensive research in recent years has revealed that most common chronic diseases, including cancer, diabetes, cardiovascular and pulmonary diseases occur as a result of free radical formation in the body. For scavenging of these free radicals cells synthesize antioxidant compounds or enzymes but they are insufficient in quantity. This increases the importance of intake of antioxidants from dietary sources which may include animal and plant based dietary components. The antioxidant activity of legumes is associated with the content of bioactive molecules, phenolic compounds in particular which include phenolic acids, flavonoids and tannins.

In India pulses are consumed in various ways and forms viz., utilized as whole, dehusked splits, milled, mixed with cereals, roasted, puffed, salted and sweetened etc. Immature pulse grains are utilized as green, roasted, boiled, fried, crushed and cooked forms. After maturity the same pulse can be consumed as dried grain, soaked, sprouted, boiled, steamed, fried, cooked as dal. Dal or sambar is prepared from dehusked cotyledons on daily basis at every household of southern India. Dehusked splits are also converted into flour to make various delicacies throughout the country. Soaking, cooking, roasting, puffing, extrusion, germination, fermentationetc., are essential processes involved in preparation of different recipes from pulses. During pulse milling, due to abrasive dehusking in commercial mills, only 70% dal is recovered against the potential dal recovery of 85%.For making biscuits 10, 20 and 30% milling by-product was incorporated in dough. The fiber and protein rich biscuits can be exploit commercial potential of milling by-product. These biscuits from pulse by-product are quite comparable with commercially available wheat fiber based biscuits.

Processing and Value addition of Oil Seeds

Oilseeds are leading suppliers of superior quality and specialty vegetable oils to nutritional products, natural food and premium snack food worldwide. Oil producing crops are corn, oat, cotton, soybean, mustard, safflower, sunflower, peanut, rapeseed, coconut, oil palm and olives. Oilseeds produced in most of the countries are mostly used for oil extraction. The oil content of small grains for example, wheat is only 1 to 2%, but that of oilseeds ranges from about 20% for soybean to over 40% for sunflower and rapeseeds like canola. The major world sources of edible seed oils are soybean, sunflower, rapeseed, cotton and peanut. Seed oils from flax (linseed) and castor bean are used for industrial purposes. They do not contain an appreciable amount of carbohydrate, but, contain high level of B vitamins. Groundnuts are particularly rich in thiamine and nicotinic acid. Oilseeds add important nutritional value to the diet due to high quality protein and or vegetable oil, together with oil soluble vitamins like vitamin A. Oilseeds, are the largest source of vegetable oils even though most oil-bearing tree fruits provide the highest oil yields (olive, coconut and palm trees). Oilseeds are also used in animal feed because of their high protein content. Their seeds contain energy for the sprouting embryo mainly as oil, compared with cereals, which contain the energy in the form of starch.

Oilseed crops are one of the great evolutionary crop products that have changed the grower's social and economic prospects and added various new food products and health-related benefits. These crops are consumed as raw seeds and also as their seed oil products. In addition, seed oil is mainly used for cooking food items, various culinary food products, and nutraceuticals. Major world oilseed crops include soybean, sesame, sunflower, Brassica, canola, coconut, oil palm, rapeseed, peanuts, rice, and cotton. The growth and development of oilseed crops, similar to other crops, requires specific growth conditions and pre-harvesting processes, including soil quality, irrigation pattern, use of soil conditioners, and many others. Similarly, the post-harvest processing of oilseed crops for obtaining good quality oil and processing waste into value-added nutraceuticals is in demand.

Various advances in biotechnology, genetic engineering, omics, etc., have provided superior seed variety for higher oil crop production yield and for obtaining high-quality oil and helped to develop disease resistance and climatic specific types. Additionally, seeds and seed oil have been widely explored for their health-related benefits; however, they possess different nutritional properties and thus signify their importance in specific health conditions. Various advances in food product development using oil/seeds have been implemented, including oil-infused products, bakery products, etc. When consumed, these products provide multiple health effects and add value to other food products when used in combination. However, efforts have also been employed to prevent seed oil oxidation, which on consumptions exert adverse health effects.

Processing and Value addition of Fruits and Vegetables

Fruits and vegetables, as well as roots and tuber crops are among the best sources of calories, natural vitamins and minerals essential for healthful living. Green leafy vegetables such as amaranth, spinach fenugreek leaves, chenopodium album (bathua), mint etc. and roots and tubers such as carrots are rich sources of beta carotene, the most important precursor of vitamin A in human nutrition Beta carotene has an important antioxidant fraction which deactivates oxygen and free radicals and thereby gives protection against cancer. Vitamin A is essential for normal growth and vision, reproduction, maintenance of epithelial cells, immune properties and its deficient intake results in a decreased levels in the blood and low levels in serum, showing sign of vitamin A deficiency. It has been observed that the current availability of fruits and vegetables meets only about half of the requirement of different vitamins and minerals and hence there is a need to boost the production and handling of vegetables and fruits, to enhance the nutrition of rural and urban poor. Therefore it becomes necessary that the processing of vegetables must be augmented by developing such techniques, which would be not only feasible but also would suffice to produce economic quality products. This makes availability of off season vegetables round the year. In India less than 2 percent of the vegetables of the total production, is being processed as against 70 percent in Brazil and 83 percent in Malaysia. The most common method for preservation of fruits and vegetables is the dehydration method. The vegetables can be dried by hot air drying method for small scale operation or by conventional tray drier or vacuum drier and at home level can be processed by sun drying method. These dehydrated forms of vegetables may be eaten as such or may be consumed in several forms, without affecting its nutrition and palatability. Vegetable powders such as carrot, tomato and fenugreek leaves powder can be prepared with simple technologies and can be incorporated in traditional food preparations, thereby adding value to the products and attaining food and nutrition security both.

Significant developments in technology include better understanding of the process of ripening of fruits, optimum harvesting time, pre-cooling of freshly harvested produce, cold storing of the raw fruits and vegetables, sorting, cleaning, waxing, packaging technology for fruits. Production of juices and value-added products including jams, jellies, pickles, canned products etc. has become a commercial success. The industry using indigenous technology includes units engaged in juice extraction, concentration of juices, canning and production of several of the products like jams, jellies, canned fruits, dried vegetables etc. These days a lot of attention is being given on health and nutrition of individuals. Today consumers demand food products, which are nutritious as well as convenient to use. Lot of focus has been given to the food products having some additional health benefits rather than the conventional products. Fruit and vegetable powders contain the natural flavor and health benefits rather than artificial food flavoring substances and they can be used as natural food additives.