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Role of innovative crop species diversification, mixed farming, polyculture, structural diversity and conservation agriculture in dry regions to end hunger & achieve sustainable development

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Abstract
Crop species diversification and Conservation agriculture plays vital role in poverty alleviation and consequently to sustainable development. 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. There is need aimed at developing optimization strategies for diversification. A sustainable agriculture approach seeks to utilize natural resources in such a way that they can regenerate their productive capacity and also minimize harmful impacts on ecosystems beyond a field's edge. Alternative ways to be less dependent on non-renewable energy sources in today's agriculture. Agroecosystems cannot be sustainable in the long run without the knowledge, technical competence and skilled labor needed to manage them effectively. Provided the constantly changing and locality-specific nature of agriculture, sustainability requires a diverse and adaptive knowledge base, utilizing both formal, experimental science and farmers' own indigenous technical knowledge. Today world faces severe shortage of food, fuel, fodder, feed and fertilizer. These shortages are only aggravating by the day, given the rapid rise in population of both humans and livestock. Sustainable livelihood creation is a way that these problems can be curbed to a certain extent. Sustainable livelihood means not only income generating activities, but creation of long lasting, ecologically stable and economically productive enterprises.

Keywords: Mixed farming, Polyculture, Structural diversity, Conservation agriculture (CA)

Introduction
Agricultural sustainability depends on the fundamental principle that we must meet the needs of the present and secure the needs of future generations. The technologies of Conservation Agriculture (CA) provide opportunities to reduce the cost of production, save water and nutrients, increase yields, increase crop diversification, improve efficient use of resources, and benefit the environment.

Center for Agri-Hort Development Institute in Manar village, district-Bhavnagar is located near the Gulf of Cambay (Gulf of Khambhat) in the Arabian Sea, a part of Saurashtra peninsula, in central part of Gujarat, India

The field research studies conducted at the Manar Center during 2017- 2019 were primarily aimed to introduce, expand, popularize Conservation agriculture, Mixed farming, Polyculture, structural diversity and precision framing for increasing productivity and sustainable development.

The research studies based on major Interventions like technical management of farm land, Conservation of Irrigation water through micro irrigation, Farm pond development, Fodder for livestock, Bio Fuel through Bio gas, Vermicomposting and other natural resources enhancing the quality of these resources have been regularly demonstrated to more than 10,000 farmers across 30 villages through field workshop, exposure visits, crop specific field days and regular farmers training at the center. Studies on Integration of Livestock welfare in overall farm management which is an integral part of progressive agriculture contributing significantly to achieve Sustainable Development.

Productivity of livestock is dependent on availability of quality nutritionally complete feed and fodder in requisite quantities. There is large shortage of green fodder and concentrates.

Production of fodder and balanced livestock feed will receive high priority to make animal production activities cost effective and remunerative to the farmers as there is great scarcity of dry fodder availability and green fodder availability for the animal husbandry in the region.

Geographical Location: Center for Agri-Hort Development Institute, Manar is situated near the Gulf of Cambay (Gulf of Khambhat) in the Arabian Sea, a part of Saurashtra peninsula, in central part of Gujarat, India.

Climate, Soil, Geology & Socio economic status: The region receives an average annual rainfall of 537 mm (IMD data) which is erratic in nature and the climate is semi-arid type. The soil is mostly found in 3 categories- i) Medium black soils ii) Alluvial soils iii) Alkaline soils.

Geology: Geologically, 80% of the area is covered by Basalts and the remaining 20 % by alluvial formation and mudflats
About 63 % of the region is cultivated of which 24 % is irrigated. The crops like ground nut, cotton, bajra, sorghum etc. are important crops of the areas. Vegetables like Brinjal, Chilies (Less pungent), Tomato, Onion are grown more. Fruits like kesar Mango, Sapota, Lemon and Guava are primarily grown by farmers.

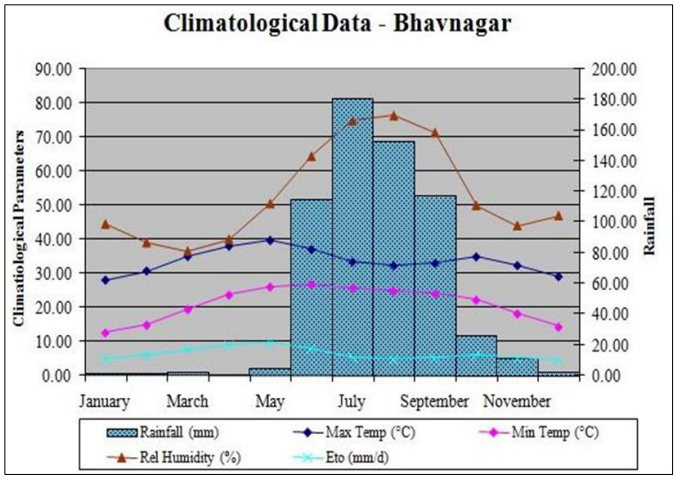

Fig 1: Source: Government of India, Ministry of Water Resources, Central Ground Water Board, West Central Region, Ahmedabad. (2013)

The Center is 2 to 2.5 kms from the sea cost. The salinity levels have reached up to 4000 TDS at some plots, major reason being excess drafting of groundwater by the farmers. The average land holding of the farmers in the region is below 2 - 5 acres.

Results and discussion

Field research studies demonstrating Innovative Crop Species diversification: The rotation of crops is not only necessary to offer a diverse "diet" to the soil microorganisms, but as they root at different soil depths, they are capable of exploring different soil layers for nutrients. In the field research we have skill fully implemented diversity within agricultural systems (genetic variety, species, structural) and over different scales (within crop, within field, landscape level). Diversification at the within-crop scale may refer to changes in crop structural diversity; using a mixture of crop varieties that have different plant heights. (Dumanski *et al*., 2006). For example, Turmeric crop intercropped in Coconut plantation not only helped maintenance of a permanent soil cover with minimum soil disturbance, less scope for weeds to grow and obtaining additional source of income. A yield of 900 kg per acre was obtained generating a value contribution of Rs. 80- 90,000 as an additional income.

Fig 2: Turmeric crop intercropped in Coconut plantation - generating additional value contribution.

Field research studies through conservation agriculture: It is a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance (i.e. no tillage), and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

Table 1: Key features of conventional and conservation agriculture systems. (Source: Dumanski *et al.* (2006) Conservation Agriculture (CA) is based on three main principles adapted to reflect local conditions and needs:

SI. No.	Conventional agriculture	Conservation agriculture
1.	Cultivating land, using science and technology to dominate nature	Least interference with natural processes
2.	Excessive mechanical tillage and soil erosion	No-till or drastically reduced tillage (biological tillage)
3.	High wind and soil erosion	Low wind and soil erosion
4.	Residue burning or removal (bare surface	Surface retention of residues (permanently covered)
5.	Water infiltration is low	Infiltration rate of water is high
6.	Use of ex-*situ* FYM/composts	Use of *in-situ* organics/composts
7.	Green manuring (incorporated)	Brown manuring/cover crops (surface retention)
8.	Kills established weeds but also stimulates more weed seeds to germinate	Weeds are a problem in the early stages of adoption but decrease with time

Fig 3: CA is based on 3 principles

1. Minimum mechanical soil disturbance: Minimum soil disturbance refers to low disturbance no-tillage and direct seeding. The disturbed area must be less than 15 cm wide or less than 25% of the cropped area (whichever is lower). There should be no periodic tillage that disturbs a greater area than the aforementioned limits. (Kassam and Friedrich, 2009) [7] Strip tillage is allowed if the disturbed area is less than the set limits. Direct seeding involves growing crops without mechanical seedbed preparation and with minimal soil disturbance since the harvest of the previous crop. (Montgomery, D.R. 2017) [9]. In Manar Center for Agri-Hort Institute we have introduced direct seeding for the first time in Fennel (*Foeniculum vulgare*) Crop intercropped with Chickpea.We obtained 950 kg seed yield recording Rs. 40000 to 45000 per acer net profit.

Fig 4: Implementation of direct seeding (Zero tillage) with Fennel Crop intercropped with Chickpea

2. Permanent soil organic cover: Three categories are distinguished: 30-60%, >60-90% and >90% ground cover, measured immediately after the direct seeding operation. Area with less than 30% cover is not considered as CA. A permanent soil cover is important to: protect the soil against the deleterious effects of exposure to rain and sun; provide the micro and macro organisms in the soil with a constant supply of "food"; and alter the microclimate in the soil for optimal growth and development of soil organisms, including plant roots. (Ghosh *et al*., 2010) [4]. At Manar Center we have cultivated Citronella-an aromatic grass which provides permanent soil organic cover and also as an intercrop between mango orchard ensuring good farm income contribution. An essential oil yield of 95 liters per acre was recorded which have a market value of RS. 90-95000. Such cover and inter crops are useful for protecting the soil, when it does not have a crop, providing an additional source of organic matter to improve soil structure, Recycling nutrients (especially P and K) and mobilizing them in the soil profile in order to make them more readily available to the following crops, provide "biological tillage" of the soil; the roots of some crops, especially cruciferous crops, like oil radish are pivotal and able to penetrate compacted or very dense layers, increasing water percolation capacity of the soil.

Fig 5: Aromatic Crop-Citronella (for essential oil production & used as powerful Mosquito and ticks repellant) grown as cover/intercrop under crop diversification giving good value addition.

3. Crop Species diversification/Crop rotation: The rotation of crops is not only necessary to offer a diverse “diet” to the soil microorganisms, but as they root at different soil depths, they are capable of exploring different soil layers for nutrients. Nutrients that have been leached to deeper layers and that are no longer available for the commercial crop, can be “recycled” by the crops in rotation. In Manar new crop French basil (*Ocimum basilicum*) is introduced. The oil is extensively used in several countries for flavouring food stuffs, confectionary goods, condiments and in toiletry products such as mouth washes and dental creams.

Fig 6: French basil (*Ocimum basilicum*) as new crop introduction and value addition

This way the rotation crops function as biological pumps. Furthermore, a diversity of crops in rotation leads to a diverse soil flora and fauna, as the roots excrete different organic substances that attract different types of bacteria and fungi, which in turn, play an important role in the transformation of these substances into plant available nutrients. (Kassam and Friedrich, 2009; Dumanski *et al*., 2006) [7].

For example Demonstration of vegetables like Brinjal (which is widely consumed in the region by farmers) as inter crop between Coconut using mulch and micro irrigation *vis-à-vis* weed management and value addition for farmers.

Fig 7: Demonstration of vegetable (Brinjal under micro irrigation production) as intercrop in Coconut through use of mulch, vis-à-vis weed management and additional source of income.

Increased structural diversity: It makes crops within the field more structurally diverse; for example, strip intercropping, which consists of the production of more than one crop in strips that are narrow enough for the crops to interact, yet wide enough to permit independent cultivation. This has been successfully demonstrated through field research conducted during last 3 years at Manar Center for Agri-Hort development Institute by growing legume Chickpea (which are high in protein) in strips as intercrop in between perennial fruit plantation of Pomegranate alongwith drip irrigation system. We recorded a yield of 10000 kg per acre of Aloe leaves and 1000 kg in Chickpea which has contributed an additional value of Rs.50-60,000 and Rs. 55,000 per acre respectively.

Fig 8: Structural Diversity with Medicinal crop *Aloe vera* and Chick pea in between fruit plantation of Pomegranate, Custard apple, Guava and Amla

Polyculture: Growing two or more crop species and wild varieties within the field. Spatial and temporal diversity of crops. At our center we have successfully grown naturally available medicinal plant species *Aloe vera barbadensis* (which requires very less irrigation water for growth and development and have high demand in Cosmetic and Ayurvedic industry) and Chickpea as intercrop in between perennial fruit plantation of Pomegranate.

Fig 9: *Aloe vera* grown as intercrop between Fruit crop Pomegranate using same input resources for main crop and generating additional source of income.

Crop rotation also plays an important phytosanitary function as it prevents the carry-over of crop-specific pests and diseases from one crop to the next via crop residues.

Fig 10: Polyculture: Three crops namely: Fruit crop Pomegranate, *Aloe vera* and Chick pea

Mixed farming: Growing of Crops and livestock. Growing of fodder crops for forage- Maize, Sorgham, Bajra, Mustard, Marvel grass (*Dichanthium annulatum*). Field research studies shows that introduction of Marvel grass as green fodder has given better results w.r.t Livestock likings since it is soft and better milk production.

Fig 11: Introduction of Marvel grass (*Dichanthium annulatum*) & Livestock development

Integration of livestock with Agri-Hort crop farming opens opportunities for sustainable Biogas production and Vermicomposting.

Biogas: Today our country especially rural and tribal areas also faces pressing challenges of fuel shortage, where the onus is on the women to collect wood for fuel. The women hits hardest by the shortage of fuel. But the distinction between "free" traditional fuels and modern "expensive" fuels has become meaningless as environmental degradation has reduced supplies and increased costs.

Fig 12: Introduced in the Center low cost Floating Dome Type-Portable Domestic Biogas unit (1 Cubic meter) can run with one live stock for one farm family saving huge cost on LPG. On monthly basis 30 CUM is equivalent 13.50 kg of LPG. The domestic LPG cylinder is 14.20 kg.

The integrated portable biogas generation unit with vermicompost established at Manar Institute ensures clean cheap fuel and is being fast replicated at farmers levels in district Bhavnagar (Gujarat). The dung from the livestock unit will be fed into the biogas plant and the output slurry which is a very good source of plant nutrients and organic carbon can be used to enrich vermibed attached to the unit. The bio gas unit helps to reduce the emission of methane thereby maintaining the ecological balance thereby. It is estimated that alternative sources of energy like bio-gas plants, may reduce the dependence on conventional sources of energy by about 20% by the turn of the century. Nearly 30% of available dung which is burnt and wasted would be recovered as bio-gas plants conserve the dung while producing bio-gas. The dung after digestion in gas plant preserves more of NPK in the dung solids and cellulose which otherwise gets lost if heaped in the open. Bio-gas slurry or FYM not only adds NPK but it proves the soil porosity and texture.

Vermicomposting

On one hand tropical soils are deficient in all necessary plant nutrients and on the other hand large quantities of such nutrients contained in domestic wastes and agricultural by products are wasted. It is estimated that in cities and rural areas of India nearly 700 million tonnes organic waste is generated annually which is either burned or land filled. Such large quantities of organic wastes generated also pose a problem for safe disposal. Most of these organic residues are burned currently or used as land fillings. In nature's laboratory there are a number of organisms (micro and macro) that have the ability to convert organic waste into valuable resources containing plant nutrients and organic matter, which are critical for maintaining soil productivity. Microorganisms and earthworms are important biological organisms helping nature to maintain nutrient flows from one system to another and also minimize environmental degradation.

Fig 13: Portable Vermicompost

The agriculture waste can be easily transformed into valuable organic manure i.e., Waste to wealth concept can be implemented.

Introduction of zero tillage

Adoption and spread of Zero Tillage in wheat has already been a success story in North-western parts of India due to (1) reduction in cost of production by Rs 2,000 to 3,000 ha-1 ($ 33 to 50) (Malik *et al*., 2005; RWC-CIMMYT,2005) [8]; (2) enhancement of soil quality, i.e. soil physical, chemical and biological conditions (Jat *et al*., 2009a) [5] (3) reduction of the incidence of weeds, such as *Phalaris minor* in wheat (Malik *et al*., 2005) [8]; (5) enhancement of water and nutrient use efficiency (Saharawat *et al*., 2012) [11]; (6) enhancement of production and productivity (4% – 10%) (Gathala *et al*., 2011a) [3]; (7) advanced sowing date (Malik *et al*., 2005) [8]; (10) providing opportunities for crop diversification and intensification-for example in sugarcane based systems, mustard, chickpea, pigeon pea etc. (Jat *et al*., 2005) [8]; (11) improvement of resource use efficiency through residue decomposition, soil structural improvement, increased recycling and availability of plant nutrients (Jat *et al*.,2009a) [5];

Field studies conducted on Zero tillage during 2017-19 at Manar Center on aromatic crops -Palma rosa (*Cymbopogon martini)* has been successfully demonstrated for the first time in the entire district. Oil of Palmarosa is obtained from the floral shoots and above ground parts.

- Palamarosa oil is one of the most important essential oils which have good demand for export.
- It is used in perfumery, cosmetics and soaps, particularly flavouring tobacco and for blending of soaps due to the lasting rose note it imparts to the blend.
- An oil yield of about 220-250 kg per hectare was recorded from second year onwards. The market price of Palma rosa oil is approx. 1200 to 1500 per kg.

Fig 14: Aromatic Palma rosa crop under ZT having high economic value

Experiences from several locations in the Indo-Gangetic plains showed that with zero tillage technology farmers were able to save on land preparation costs by about Rs. 2,500 ($41.7) per ha and reduce diesel consumption by 50 – 60 litres per ha (Sharma *et al*., 2005) [6]. Zero tillage allows timely sowing of wheat, enables uniform drilling of seed, improves fertilizer use-efficiency, saves water and increases yield up to 20%. Success has also been achieved in bed planting of wheat, cotton and rice. This has resulted in savings in irrigation water, improved fertilizer use and reduced soil crusting.

The effects of crop rotation

- Higher diversity in plant production and thus in human and livestock nutrition.
- Reduction and reduced risk of pest and weed infestations.
- Greater distribution of channels or biopores created by diverse roots (various forms, sizes and depths).
- Better distribution of water and nutrients through the soil profile.
- Exploration for nutrients and water of diverse strata of the soil profile by roots of many different plant species resulting in a greater use of the available nutrients and water.
- Increased nitrogen fixation through certain plant-soil biota symbionts and improved balance of N/P/K from both organic and mineral sources.
- Increased humus formation.
- Design and implementation of crop rotations according to the various objectives: food and fodder production (grain, leaf, stalks); residue production; pest and weed control; nutrient uptake and biological subsurface mixing / cultivation, etc.
- Use of appropriate / improved seeds for high yields as well as high residue production of above-ground and below-ground parts, given the soil and climate conditions.

In the face of changing weather driven by climate change and the increasing demand for food, Conservation Agriculture (CA), Mixed farming, Poly culture and Structural diversity aims to achieve sustainable and profitable agriculture and improve farmers' livelihoods which are given below:

Main focus areas in dry regions that needs to be addressed

- Climate-resilient crops and livestock that help farmers cope with drought, extreme heat, pests, disease, and other stresses.
- Water-saving technologies and more efficient irrigation regimes that enhance water productivity and guarantee "more crop per drop."
- Proven agronomic practices that promote the sustainable management of natural resources such as conservation agriculture.
- Integrated crop–livestock farming systems that cushion each sector from external pressures and generate maximum effects from a symbiosis of both.
- Promoting sustainable value chains and off-farm activities: diversifying production; promoting value-added products; enhancing market access for smallholder farmers; and supporting the viability of alternative livelihoods.
- Capacity development: equipping farmers, communities, and institutions with the knowledge and experience to transform agricultural development and strengthen resilience.
- Conservation agriculture is by no means a low output agriculture and allows yields comparable with modern intensive agriculture but in a sustainable way. Yields tend to increase over the years with yield variations decreasing.
- Reduced costs. For the farmer, conservation farming is mostly attractive because it allows a reduction of the production costs, reduction of time and labour, particularly at times of peak demand such as land preparation and planting and in mechanized systems it reduces the costs of investment and maintenance of machinery in the long term.

Inference

Theses studies conducted on the Role of Innovative Crop Species Diversification, Mixed farming, Polyculture, Structural diversity and Conservation Agriculture in Dry regions mainly offers a new paradigm for agricultural research and development different from the conventional one, which mainly aimed at achieving crop specific production targets. A shift in paradigm has become a necessity in view of widespread problems of resource degradation, which accompanied the past strategies to enhance production with little concern for resource integrity. Integrating concerns of productivity, resource conservation and soil quality and the environment is now fundamental to sustained productivity growth. Developing and promoting above systems will be highly demanding in terms of the knowledge base. This will call for greatly enhanced capacity of scientists to address problems from a systems perspective; be able to work in close partnerships with farmers and other stakeholders and strengthened knowledge and information-sharing mechanisms.

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