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IAEA-TECDOC-1840

Cassava Production Guidelines for Food Security and Adaptation to Climate Change in Asia and Africa

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

IAEA
International Atomic Energy Agency

CASSAVA PRODUCTION GUIDELINES FOR FOOD SECURITY AND ADAPTATION TO CLIMATE CHANGE IN ASIA AND AFRICA

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CASSAVA PRODUCTION GUIDELINES FOR FOOD SECURITY AND ADAPTATION TO CLIMATE CHANGE IN ASIA AND AFRICA

PREPARED BY THE
JOINT FAO/IAEA DIVISION OF NUCLEAR TECHNIQUES IN FOOD AND AGRICULTURE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2018

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Printed by the IAEA in Austria
June 2018

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Cassava production guidelines for food security and adaptation to climate change in Asia and Africa / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2018. | Series: IAEA TECDOC series, ISSN 1011–4289 ; no. 1840 | Includes bibliographical references.
Identifiers: IAEAL 18-01153 | ISBN 978–92–0–101718–5 (paperback : alk. paper)
Subjects: LCSH: Stable isotopes in soil fertility research. | Cassava — Climatic factors. | Cassava as food. | Food security.

FOREWORD

Cassava (*Manihot esculenta*) is the third largest source of carbohydrates for humans and animals in the tropics, after rice and maize. People consume the cassava roots as a source of calories, while the leaves are eaten as a nutritious vegetable. Cassava is a major food crop in Africa, and both dry root chips and leaf silage are excellent feed for animals. However, declining soil fertility and soil erosion are serious problems on traditional cassava farms in both Africa and Asia, and together with climate change, have an adverse impact on cassava production in both continents.

This publication was prepared following a special request from Member States in Africa and Asia working together in IAEA technical cooperation projects to enhance cassava production. It provides information on the best farm management practices and the use of nuclear and isotopic techniques to better understand nitrogen use efficiency. The guidelines will enable farmers to adapt their cassava production methods to a wide range of soil and agroclimatic conditions. This publication also provides an integrated crop management plan that addresses nutrients, weeds, insect pests and disease. By using improved crop management methods, farmers can optimize cassava yields and minimize production costs. The methods can also help to reduce or prevent land degradation caused by soil erosion, particularly on sloping lands, thereby protecting the local environment.

This publication also details the development and use of improved cassava varieties with lower levels of cyanogenic glucosides and varieties of fortified with vitamin A, iron and protein. Their use will primarily improve nutrition of individuals in sub-Saharan Africa and some countries of Asia where cassava root is a main source of carbohydrates. Finally, the guidelines emphasize the importance of a timely harvest and proper post-harvest processing of cassava roots and leaves into a range of products including food and animal feed, but also for industrial materials such as cassava starch, feedstock for biofuel and even a biopesticide made from cassava leaves. The IAEA officer responsible for this publication was M. Zaman of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture.

EDITORIAL NOTE

CONTENTS

SUMMARY

Cassava (*Manihot esculenta*) is the primary source of carbohydrates for the poor people of the tropics. It is replacing upland rice in many Asian countries, and is a major food crop in Africa. People and livestock consume mostly the cassava roots as a calorie source, while cassava leaves are eaten as a nutritious vegetable by some people. Both dry root chips and leaf silage are excellent feedstocks for animals - up to 30% of their daily ration.

Cassava is a hardy crop that can survive even in poor soils and a varying climate, though root yields are very low (2–3 metric tons per hectare). In addition, continuously declining soil fertility and the increasing soil erosion which accompanies a changing climate pose serious problems to cassava production in both Asia and Africa.

This IAEA Guidelines for improving cassava production in Asia and Africa is designed to help farmers to adapt their cassava production practices to different soil and agroclimatic conditions that are expected to accompany a changing climate. It also highlights the use of isotopic techniques to study nitrogen use efficiency. Key improved cassava production practices are given below.

Improved cassava varieties: Plant the best available locally adapted 'improved' cassava varieties. Improved cassava varieties will have lower cyanogen glucosides and be fortified with vitamin A, iron and have higher protein levels. Their use will help improve the nutrition of mainly the poor, who consume cassava roots as their main source of carbohydrate.

Preparing healthy planting materials: Plant healthy, disease-free, 15–20 cm long stem cuttings. Prepare the stem cuttings only from high-yielding cassava mother plants that are 8-12 months old. Take the lower and middle parts of the stems for preparing cuttings. For most cassava varieties, these cut stems can be stored vertically in the shade for 1–2 months before planting in the soil.

Land configuration: Flat land is plowed, harrowed, leveled, and 75–100 cm wide ridges are formed either manually or with the help of furrow openers attached to a tractor. The furrows are made to gently slope along the natural slope of the field to help drain excess rainwater, if necessary.

On sloping lands, it is better to establish hedgerows of grasses such as *Paspalum atratum* or *Tephrosia candida* or plant pineapple across slopes, with the cassava crop located between the hedgerows. This will reduce soil erosion and improve rainwater infiltration into the soil.

Planting: The general spacing is 75 to 100 cm between rows or ridges and 50 to 75 cm between planting holes within the rows or ridges for a mono-crop of only cassava. A wider spacing of up to 200 cm between rows or ridges is used when cassava is intercropped along with 1 to 3 rows of fast-growing legumes, or with a cereal crop like maize or millet. The cassava stem cuttings can be planted vertically, or in a slanted position by pushing the lower part of the cutting 5–10 cm deep into the soil. Alternatively, stem cuttings can be planted horizontally at a 5–7 cm depth. Missing plants, if any, should be replaced within 2–3 weeks from the original date of planting.

Rainfall management: In rain fed areas, farm ponds can be dug to collect rainwater which later can be used to wet the crop during periods of severe drought (life-saving irrigation).

Mulching of the soil surface with crop residues or grass clippings will help reduce soil erosion, suppress weed growth, and enhance infiltration of rainwater into the soil, thereby reducing evaporation of soil moisture.

Water-saving irrigation methods: Wherever water is available, the cassava crop can be irrigated by flood, furrow or drip irrigation. Drip is more water-efficient than furrow irrigation which in turn is better than flood irrigation.

Balanced fertilizer application: is critical not only to increase crop yields, but also to increase starch content in roots. In most soils cassava responds well to potassium, nitrogen and phosphorus applied in the following order of magnitude: K >N >P. Crop residues returned to the soil and mineralization of soil organic matter may supply part of the N, P, and K requirements of the crop. As a general rule, farmers will apply 2 kg N, 0.7 kg P_2O_5, and 2 kg K_2O per hectare for every metric ton of cassava root yield. All the P and half of the N and K can be applied at planting, while the remaining N and K are applied 2-3 months after planting. The fertilizer can be band-applied near the crop rows, or spot-applied 5-10 cm from the base of each plant.

In problem soils, before applying fertilizers, soil amendments will need to be applied to correct specific problems, such as soil acidity, aluminum toxicity, salinity, and very low levels of soil organic matter.

Integrated weed management: An effective program of weed control is critical during the early growth period (up to 3 months after planting) in order to prevent yield losses due to weed competition. Use of a highly effective combination of cultural, manual, mechanical and/or chemical weed control methods is recommended.

Integrated pest management (IPM): The three cardinal principles of IPM are: (i) growing **a healthy crop** by adopting resistant varieties and using best crop management practices; (ii) **maintaining pest-predator balance** by establishing a healthy agro-ecosystem; and (iii) the **strategic use of external pest control inputs** that are known to have a minimal impact on the agro-ecosystem.

Harvesting and postharvest processing: Cassava can be harvested as and when required, between 6 - 8 and 18 months after planting (MAP). Both root and starch yields triple between 8 and 18 MAP.

Mechanization: Using improved tools for harvesting cassava roots, for slicing roots to make dry chips, and for chopping cassava leaves for producing silage can increase labor productivity, reduce drudgery, and increase profitability in cassava farming.

If followed correctly, the above best management practices have the potential to increase yields, minimize processing losses of cassava roots, and enhance the quality and market value of cassava products.

1. INTRODUCTION

Cassava (*Manihot esculenta*) is a tropical root crop that is known by different names – Brazilian arrow root, manioc, tapioca, or yucca. It is a woody shrub native to South America and a member of the *Euphorbiaceae* family. It is extensively cultivated in tropical and subtropical regions for its edible starchy tuberous roots. It is the 3rd largest source of food carbohydrates in the tropics after maize and rice. The cassava plant gives the third highest yield of carbohydrates per unit area among crop plants, after sugarcane and sugar beets. It can produce food calories at rates exceeding 250 000 calories per hectare per day compared with 176 000 for rice, 110 000 for wheat, and 200 000 for maize.

The cassava root is long and tapered, with a strong, homogeneous flesh encased in a detachable rind, the rind being about 1 mm thick, rough and brown on the outside. Roots of improved commercial varieties can be 15 to 45 cm long and 5 to 10 cm in diameter at the top. A woody vascular bundle runs along the root's axis. The flesh can be white or yellowish. Cassava roots are very rich in starch and contain significant amounts of calcium (50 mg per 100 g), phosphorus (40 mg per 100 g) and vitamin C (25 mg per 100 g). However, they are low in protein and other nutrients. In contrast, cassava leaves are a good source of protein (rich in lysine but deficient in the amino acid methionine and often tryptophan) [1].

Cassava varieties can be classified as either sweet or bitter. Like many other roots and tubers, both bitter and sweet varieties of cassava contain anti nutritional factors and toxins, with the bitter varieties containing much larger amounts. The roots and leaves must thus be properly prepared before consumption, as improper preparation of cassava can leave enough residual cyanide to cause acute cyanide intoxication, gaiters, and even ataxia or partial paralysis [2].

Cassava is a major food crop for more than 700 million people, especially in Sub-Saharan Africa (SSA) and in developing countries of Asia such as Cambodia, Lao P.D.R. and Viet Nam. Cassava offers the flexibility of either serving as the food crop of the last resort for the resource poor farmers, or as a cash crop where production, processing and marketing opportunities exist [3]. The relative tolerance of cassava to droughts and even short term flooding make it an excellent crop to resist the negative impacts of climate change. It is thus important in several ways: for tackling hunger in a world of changing climate, as a source of food security when and where all other crops fail, as a means to create cash income through cassava processing and sales, as a driver for local agro-industry, as a way of reducing the cost burden to national governments on imports of foods, as a source of starch for various industrial uses, and as a potential export crop, especially as livestock and chicken feed. Thus, the importance of cassava is growing in SSA and parts of Asia for food security, development of rural agroindustry, and for employment and income generation.

Using a range of nuclear and isotopic techniques, the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture is promoting climate smart agricultural practices that are designed to assist farmers in Member States to find integrated solutions to increase crop productivity through better resource use efficiency (nutrients and water). These latter objectives, minimising losses of nutrients to the atmosphere as greenhouse gases, and nutrient losses via surface runoff and leaching to water bodies, can be accomplished by enhancing soil fertility, sequestering more atmospheric carbon to make soil more resilient against climate change and thus more productive. Isotopic technique such as use of ^{15}N allows to precisely measure fertiliser use efficiency, identify N uptake sources, i.e., from the soil and from applied N fertilisers, and additionally to quantify the fixation of atmospheric N_2 by legumes.

2. HISTORY OF CASSAVA

Cassava was likely first domesticated more than 10 000 years ago in west central Brazil [4]. Forms of the modern domesticated cassava species can also be found growing in the wild in the south of Brazil. By 4 600 BC, it had become a staple food of the native populations of northern South America, southern Mesoamerica, and the Caribbean. Mass production of Casabe (cassava) bread became the first Cuban industry established by the Spanish. Cassava was introduced to Africa and Asia by Portuguese traders from Brazil in the 16th century. Cassava is sometimes described as the 'bread of the tropics' [5]. It is now widely grown as in important food and industrial crop throughout the tropics.

3. CASSAVA PRODUCTION ENVIRONMENTS AND PRODUCTIVITY

Cassava is well adapted within the latitudes 30° north and south of the equator, at elevations between sea level and 2 000 m above sea level, in equatorial temperatures, with annual rainfalls ranging from 50 mm to 5 000 mm, and to poor soils with a pH ranging from acidic (pH 4.5) to alkaline (pH 8.0). These conditions are common in certain parts of Africa, Asia, and South America. As mentioned above, it is highly resilient to climate change, and can be successfully grown on marginal soils, with reasonable yields where many other crops fail to grow and produce any yield. However, it produces high yields in fertile soils under good crop management. The potential maximum yield of cassava is estimated to be 80 ton (t) per hectare (ha) of fresh roots (29 t ha^{1} of dry roots), while the attainable yields can be above 30 t ha^{-1} of fresh roots. The most productive cassava farms in the world are found in India, with a national average yield of 35.65 t ha^{-1} in 2014 [6]. Under poor field conditions, the yields could be as low as 2–3 t ha^{-1}, while cassava productivity has increased to a national average yield of 12 t ha^{-1} in Nigeria and 6 to 12 t ha^{-1} in other counties of Africa. Still, there is a huge potential for increasing cassava yields further, given that there is a large gap between the farmers' current cassava yields and the attainable or potential yields. With the need for intensifying cassava production in areas where population densities have reduced access to fallow land and with cassava roots becoming important raw material for the processing sector, this yield gap needs to be reduced for the benefit of farmers, processors, and the common public.

4. CASSAVA PRODUCTION STATISTICS

Globally, in 2013–2014, the area planted to cassava was 24.22 million (m) ha, the production was 270.3 m t, and the mean yield was 11.16 t ha^{-1}. Africa was the top producer of cassava with 54.5% share of the global cassava production, followed by Asia with 33.5%, and the Americas with 11.9% (FIG. 1). In 2014, the mean yield of cassava was only 8.38 t ha^{-1} in Africa, compared to 21.86 t ha^{-1} in Asia (Table 1). Although Nigeria is still the global leader in production of cassava (54.83 m t in 2014), the national average yields of cassava in Nigeria are only about half of those of leading cassava producers in Asia, and less than half of the yields of researcher run trials in the country. In terms of cassava production, Nigeria was followed by DR Congo (16.61 m t), Ghana (16.52 m t), Angola (7.64 m t), and Mozambique (5.11 m t). In Africa, Malawi produced the highest cassava yield of 23.36 t ha^{-1} in 2014, followed by Ghana (18.59 t ha^{-1}), and Angola, DR Congo and Nigeria (7.72 to 10.10 t ha^{-1}) (Table 1).

An estimated 8 million farmers grow cassava on more than 4 million hectares in Asia. In 2014, Thailand was the largest producer with 30 m t per annum, followed by Indonesia (23.4 m t), Vietnam (10.21 m t), Cambodia (8.83 m t), India (8.14 m t) and China (4.68 m t).

The most productive cassava farms in the world are found in India, with a national average yield of 35.65 t ha^{-1} in 2014 [6]. However, Thailand is the largest exporting country of dried cassava chips and cassava starch, with a total of 77% of the world export in 2005. The second largest exporting country is Vietnam, with 13.6%, followed by Indonesia (5.8%) and Costa Rica (2.1%). China is the largest importer of dried cassava chips and cassava starch produced in Thailand and Vietnam. Other countries importing significant amounts of dried cassava are South Korea, Spain and Belgium, while the countries importing cassava starch include Indonesia, Japan and Malaysia. Outside Asia and Africa, Brazil is the largest producer of cassava with an annual production of 23.24 m t in 2014.

TABLE 1. CASSAVA AREA, PRODUCTION, AND YIELD IN SELECTED COUNTRIES OF AFRICA AND ASIA AND BRAZIL (2014) [6]

Country	Area (m ha)	Production (m t)	Yield (t ha^{-1})
World	24.22	270.29	11.16
Africa	17.52	146.82	8.38
Nigeria	7.10	54.83	7.72
DR Congo	2.06	16.61	8.08
Ghana	0.89	16.52	18.59
Angola	0.76	7.64	10.10
Mozambique	0.87	5.11	5.88
Tanzania	0.80	4.23	5.28
Uganda	0.85	2.81	3.30
Malawi	0.21	4.91	23.36
Asia	4.13	90.37	21.86
Thailand	1.35	30.02	22.26
Indonesia	1.00	23.44	23.36
Viet Nam	0.55	10.21	18.47
Cambodia	0.36	8.83	24.57
India	0.23	8.14	35.65
China	0.29	4.68	16.27
Brazil	1.57	23.24	14.83

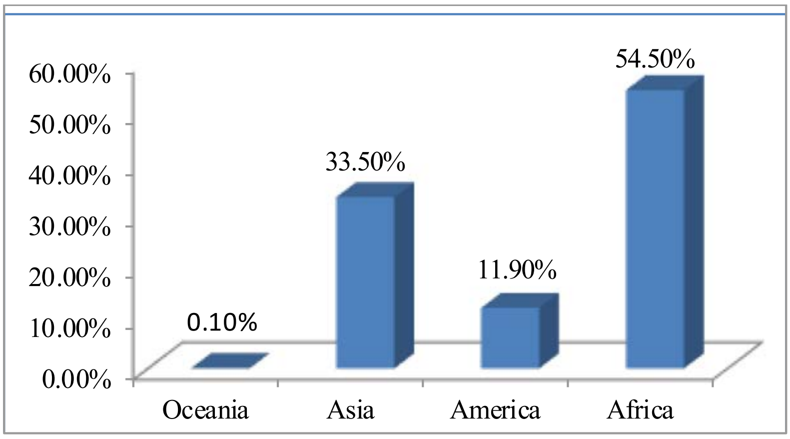

FIG. 1. Share of cassava production by region in 2013–2014 [6].

NB: m ha = million hectares; m t = million tons; t ha^{-1} = tons per hectare

5. MULTIPLE USES OF CASSAVA

5.1. FOOD AND BEVERAGES

Cassava is an important staple food for over 700 million people, mostly in SSA. In Nigeria, 90% of the cassava roots is used for direct food and processed food products, leaving only 10% to be converted for industrial uses. The presence of cyanide in cassava roots is of concern for human and for animal consumption. Once harvested, the bitter cassava must be detoxified by proper processing prior to human or animal consumption [7], while sweet cassava can be used after simple boiling. Fermentation is the main process used for detoxifying cassava roots or cassava flour. The cassava flour is mixed with water to make a thick paste which is made into a thin sheet spread over a basket and let stand for 5–6 hours to detoxify the flour [8]. In West Africa, cassava roots are peeled, washed, fermented in water for 3 days, and dried before processed into various food stuffs.

The root of the sweet variety has a delicate flavour and can replace potatoes in certain food preparations. For example, it is used as a substitute for potato in *cholent* (a traditional Jewish stew prepared for Shabbat) in some households. In Brazil, detoxified manioc is ground and cooked to a dry, often hard or crunchy meal known as *farofa* used as a condiment, toasted in butter, or eaten alone as a side dish. In West Africa, the fermented roots are grated and lightly fried in palm oil to preserve them. The resultant foodstuff is called *gari* which is flaky and light yellow in colour. Fermentation is also used to detoxify cassava roots and to prepare a traditional alcoholic fermented food called *tapai* in Indonesia. Cassava starch is processed into noodles and eaten in Cambodia. In India, roots of sweet cassava varieties are peeled, washed, cut into pieces and steamed before eating either alone with side dishes or with other foods (FIG.2).

Cassava, when processed into a white powder or small round pearls, is called tapioca. Detoxified cassava flour or tapioca is used for making breads, cakes and cookies in many countries (FIG.2). Tapioca, being a pure starch, is considered a complex carbohydrate, making it a great way to maintain energy levels throughout the day. The high level of dietary fibre found in tapioca helps move food through our digestive tract, which alleviates gas problems, including bloating and flatulence, prevents constipation and intestinal pain, and even reduces the risk of colon cancer. Furthermore, the dietary fibre scrapes bad cholesterol off of the arterial walls, reducing the risk of heart attacks and strokes. Tapioca is rich in iron, which plays a vital role in forming red blood cells and improving oxygen flow in the body. The high levels of iron and calcium in tapioca help in the protection and development of bones in the body.

Cassava root is essentially a carbohydrate source. Its composition shows 60–65% moisture, 20–31% carbohydrate, 1–2% crude protein and a comparatively low content of vitamins and minerals. However, the roots are rich in calcium (50 mg per 100 g), phosphorus (40 mg per 100 g) and vitamin C (25 mg per 100 g), and also contain a nutritionally significant quantity of thiamine, riboflavin and nicotinic acid. However, methionine, cysteine and cystine are the limiting amino acids in cassava roots. Cassava starch contains 70% amylopectin and 20% amylose. Cooked cassava starch has a digestibility of over 75%. Recently, a project called "BioCassava Plus" is developing a cassava with lower cyanogen glucosides and fortified with vitamin A, iron and protein to help the nutrition of people in sub-Saharan Africa [9]

FIG. 2. Different types of cassava (tapioca) foods prepared and eaten by people around the world. (a) Peeled and washed cassava roots, (b) cooked cassava roots (Kerala, India), (c) cassava noodles (Cambodia), (d) cassava (tapioca) flour, (e) cassava/Tapioca pearls (called sago in India), (f) cassava pudding (baby food), (g) cassava fried chips, (h) cassava cake and (i) cassava bread.

Apart from the roots, cassava leaves are a good source of protein [1]. Scientific studies show that 100 g of cooked cassava leaves provides about 3.7 g of protein which is pretty good for a green leafy vegetable. They contain essential amino acids such as lysine, isoleucine, leucine, valine, and lots of arginine, and certain vitamins – which are not common in green leafy plants thus making cassava leaves a great source of protein and vitamins. However, the leaves are deficient in the amino acid methionine and possibly tryptophan. Frozen cassava leaves prepared in the Philippines are exported to and sold in the supermarkets in the USA (FIG.3).

FIG. 3. Frozen cassava leaves from the Philippines sold at a Los Angeles market in the USA.

Alcoholic beverages made from cassava include Cauim and tiquira (Brazil), kasiri (Sub-Saharan Africa), Impala (Mozambique) masato (Peruvian Amazonia chicha), parakari or kari (Guyana), nihamanchi (South America) aka nijimanche (Ecuador and Peru), ö döi (chicha de yuca, Ngäbe Bugle, Panama), sakurá (Brazil, Surinam).

5.2. AS A LIVESTOCK AND POULTRY FEED

Cassava tubers and hay are used worldwide as animal feed. Cassava hay is harvested at a young growth stage (three to four months old) when the plants reach 30 to 45 cm in height; it is then sun dried for one to two days until it has a final dry matter content of less than 85%. Cassava hay contains high levels of protein (20–27% crude protein) and condensed tannins. It is valued as a good roughage source for ruminants such as cattle [10]

Cassava meal or pellets prepared from roots is used as a substitute for maize or other grains up to 20% of the grains in chicken feed. Low hydrogen cyanide (HCN) sweet cassava varieties are preferred for chickens; other bitter varieties containing high HCN should be detoxified by proper treatment and processing before used in chicken feed. For every 1000 kg of fresh cassava roots, we can get 250 kg of cassava flour or pellets. Addition of animal fat and soybean flour makes cassava based rations isocaloric and isoproteinaceous and increases the digestibility of the protein in the feed.

5.3. INDUSTRIAL STARCH

Cassava roots are now processed into various products such as starch, high quality cassava flour, glucose, and even bioplastics. Cassava starch is used in a number of commercially available laundry products, especially as starch for shirts and other garments. Using manioc starch diluted in water and spraying it over fabrics before ironing helps stiffen collars. Research is ongoing to develop mutant cassava varieties with waxy starch content that can be used for developing bioplastics from sago like sticky cassava flour.

5.4 AS A FEEDSTOCK FOR BIOFUEL (RENEWABLE ENERGY)

In many countries in search of suitable feedstock for renewable energy production, significant research has begun to evaluate the use of cassava as a non-grain ethanol biofuel feedstock. The diagram in FIG.4 shows the cassava flour to ethanol processing flow. In China, cassava (tapioca) chips have gradually become a major source for ethanol production. On December 22, 2007, the largest cassava bioethanol plant was completed in Beihai, with annual output of 200 thousand tons, which would need an average of 1.5 million tons of cassava. Six cassava starch based ethanol refineries have been started in

Vietnam with a total capacity to produce 550 million litres per year. There is at least one factory in Nigeria that produces ethanol from cassava starch.

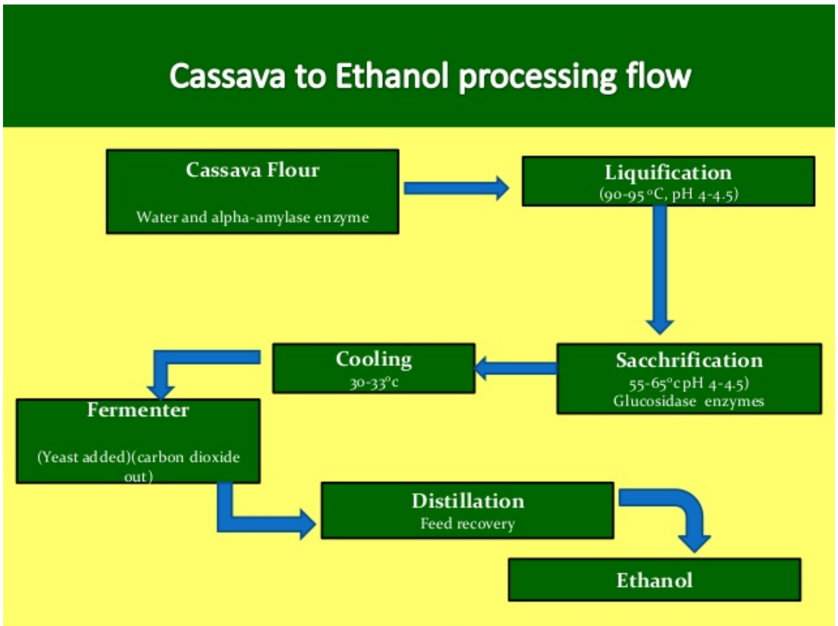

FIG. 4. Cassava flour to ethanol processing flow diagram.

5.5. MEDICINAL USES

Cassava root has been considered as a possible treatment for bladder and prostate cancer [11]. However, according to the American Cancer Society, "there is no convincing scientific evidence that cassava or tapioca is effective in preventing or treating cancer".

5.6. NANMA: A CASSAVA BASED BIO-PESTICIDE

Cassava leaves of bitter varieties contain a toxin i.e. cyanogenic glucoside that helps to control the insect pests of certain crops. The cassava based bio pesticide, Nanma, developed from cassava leaves has been found to be effective against noxious borer pests of vegetables like eggplants. Eight litres of the bio pesticide can be produced from one kilogram of cassava leaves. Nanma @ 10 ml per litre of water was found most effective against the reduction of shoot as well as fruit damage caused by deadly borer pest of eggplants (Information source: Mr. T. Saha, Assistant Professor cum Jr. Scientist, Department of Entomology, Bihar Agricultural College, Sabour, India).

6. CONSTRAINTS TO CASSAVA PRODUCTION IN ASIA AND SUB-SAHARAN AFRICA

Cassava is a highly resilient crop that can be grown in harsh environments when adequate nutrients are added to the soil. On marginal soils with low and variable rainfall, the yield could be low (2–3 t ha^{-1}). Although not a 'nutrient hungry crop' like maize, a cassava crop does require adequate supply of nutrients and water to obtain high and sustainable yields under intensive cultivation. In reality, like any other crops, cassava production is affected by a number of abiotic, biotic, management, and socioeconomic constraints across Asia and Africa.

6.1. ABIOTIC CONSTRAINTS

The problem of soil fertility decline is serious in many areas, including the fragile uplands and high altitude areas of Asia and Africa. For example, phosphorus (P), potassium (K) and nitrogen (N) deficiency (FIG.5) are severe in continuous cassava production systems with inadequate supply of nutrients.

Being highly resilient to variable moisture stress, cassava can grow in areas with as little as 500 mm annual rainfall and can survive dry periods of 5–6 months. The crop adapts to soil water shortages through various mechanisms, such as shedding leaves, closing stomata, osmotic adjustment, increasing root length, and decreasing the leaf area [12]. However, severe drought stresses can curtain cassava productivity drastically, as result of reduced growth and biomass production, impaired reproduction processes and decreased assimilate portioning, and poor root development. When cassava plants were subjected to a soil moisture stress at 25% of field capacity, stem elongation of cassava plants was halved, and the biomass yields were reduced by 87% and root yields by 95% [13]. Breeding programs are now providing to farmers new drought tolerant cassava varieties and it can help expand cassava cultivation into non-traditional semiarid regions of SSA and Asia.

Pre-treatment of cassava plants with the plant growth regulator glycine betaine can alleviate the negative effects of drought stress in semiarid areas as well as the impacts of cold stress in subtropical areas [14]. However, unless the cost of glycine betaine is reduced appreciably, this approach will likely not be of significant economic benefit.

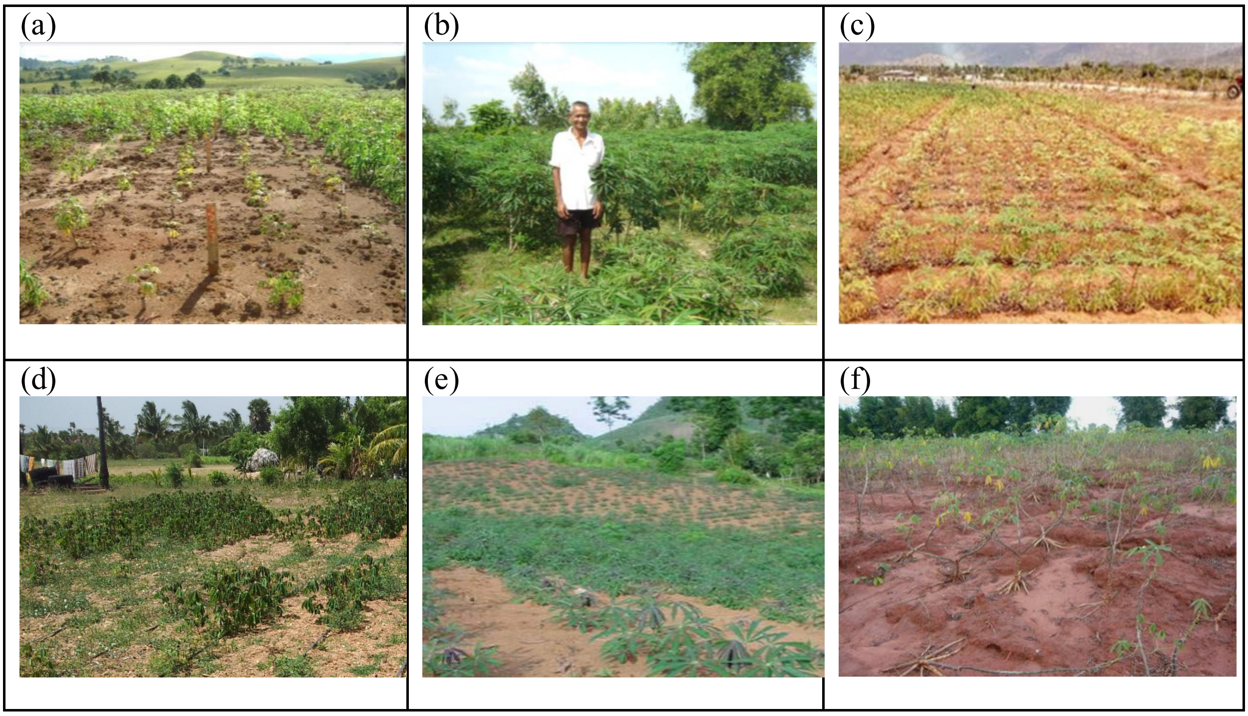

FIG. 5. Abiotic stresses affecting cassava production in Asia and Africa. (a) P deficiency in cassava (Xieng Khouang, Laos), (b) K deficiency (Cambodia), (c) N deficiency (Usilampatti, Tamil Nadu, India) (d) drought stress (Sangagiri, Tamil Nadu, India), (e) monocrop cassava on sloping land with high risks of soil erosion (Viet Nam), (f) soil erosion in monocrop cassava fields

The planting of cassava with wide spacing (1 m x 1 m) leaves the ground open for erosion (FIG. 5) during the first 3–4 months after planting, especially on sloping lands. The steeper the slope, the greater is the soil loss. In addition, expansion of cassava cultivation to marginal lands without proper soil and water management has led to soil degradation in many parts of Asia and Africa

6.2. BIOTIC CONSTRAINTS

Biotic constraints include insect pests and diseases that attack cassava plants. In SSA, cassava is affected by insect pests such as whiteflies, mites, mealybugs and grasshoppers and diseases such as African cassava mosaic disease (CMD), cassava brown stream virus (CBSV), cassava bacterial blight (CBB), and cassava root rots. In Asia, the cassava crop is affected by insect pests like whiteflies, mites, mealybugs and white grubs and diseases like root rots, cassava bacterial blight, and phytoplasma diseases. Details of these pests and diseases will be discussed under the section on Cassava pests and diseases.

6.3. MANAGEMENT CONSTRAINTS

- Lack of knowledge of improved high yielding cassava varieties with longer shelflife and resistance to local pests and diseases and their production technologies, use of poor quality stem cuttings (seed) to establish a new crop, poor or no organization of farmers into cassava producer groups, and poor marketing strategies for cassava products constrain cassava production in both Asia and Africa.
- Despite having very poor soils, soil quality improvement is inadequately addressed in most parts of Asia and Africa. There is no regular soil testing and/or monitoring of changes in soil fertility under continuous cultivation of cassava. Inadequate and unbalanced application of nutrients leads to soil degradation, acidification followed by weed infestation in these nutrient depleted soils, which in turn lead to low crop yields.
- Failure to improve soil organic matter content, especially in SSA, no amelioration of the soil's microbial population and activity, poor water holding capacity, and an inadequate supply of micronutirents to crops also contribute to low cassava yields.
- Poor management of the soil and water resources, especially on sloping lands – e.g., soil ersoion and poor infiltration of rainwater into the soil due to the absence of soil erosion control measures and the lack of adoption of conservation agrciulture practices, and the lack of rainwater harvesting and development of farm ponds for providing supplemental irrigation during periods of drought.
- Other agronomic constraints include excessive tilling of land, use of inefficient monocoulture cropping systems (as against crop rotation, intercropping, diversified farming, etc.), poor pest and disease control, and inefficient handling, storage, and transport of fresh cassava roots.
- Farmers also are not particularly concerned with environmental problems like the generation of cassava wastes and emission of greenhouse gases during processing of cassava roots and development of cassava products.

6.4. SOCIO-ECONOMIC AND POLICY CONSTRAINTS

- Smallholder farmers operate within a variety of agroecological, economic and social contexts.
- Poor access to capital and/or low interest credit to develop new cassava farms.
- Poor agricultural extension support to farmers, particularly with the distribution of heathy plantiing materials and provision of critical inputs.

- Low profits due to increasing production costs and decreasing revenue due to inconsistent product quality and unrelaible supply of cassava products.
- Farmers' inability to buy and apply chemical fertilisers to cassava crops, thereby resulting in declining soil fertility and low crop yields.
- The location of cassava processing centers far away from cassava production areas.
- Poor integration fo smallholder cassava farmers in the cassava value chian, especially the poor access to markets.
- Ensuring that the processing industry manages waste in an efficient and environmentally responsible way. Using waste as a source of biogas or animal feed, for example, would be a step in the right direction.

7. CASSAVA VALUE CHAIN VS. SMALLHOLDER FARMERS: STATUS, CONSTRAINTS AND OPPORTUNITIES FOR IMPROVEMENT

The harvested fresh roots of cassava are bulky, and have a short shelf life. Cassava roots undergo what is called the postharvest physiological deterioration (PPD). PPD is one of the main obstacles currently preventing farmers from commercializing the cassava crop. Fresh cassava can be preserved like potato, using thiabendazole or bleach as a fungicide, then wrapping in plastic, coating in wax or freezing; but such processes are beyond the reach of marginal cassava farmers. The three key barriers that highlight the short shelf life issues are: (a) lack of farmers' knowledge of and limited access to improved cassava varieties with extended shelf life; (b) poor and inefficient handling, storage, and transport of fresh cassava roots after harvest; and (c) the location of cassava processing centres far away from cassava production areas. All the three issues have to be addressed to reduce postharvest losses and to improve product quality after processing.

Over the years, cassava has been transformed from being a "poor man's" crop to cash and an industrial crop, as it is now processed into products such as starch, flour, glucose, and ethanol. This transition has increased the demand for this root crop. However, there is a large disconnect between small scale cassava producers and the large demand for cassava starch in many African and Asian countries. Thus, developing more inclusive and sustainable cassava value chains is especially important for reducing the poverty among and to improve the wellbeing of the poor and marginal cassava farmers in Africa and Asia. For example, the 'Cassava: Adding Value for Africa' project has supported the development of value chains for high quality cassava flour (HQCF) in Ghana, Tanzania, Uganda, Nigeria, and Malawi to improve the incomes and livelihoods of smallholder households, including women [15]. The project focuses on three key interventions: 1) ensuring a consistent supply of raw materials; 2) developing viable intermediaries as secondary processors or bulking agents; and 3) driving market demand for cassava products. The main objective of the business model is to assess the viability of centralizing factories for processing high quality cassava flour in the urban centres while primary processing of dried cassava chips is decentralized and sourced at village levels. This business model aims at reducing post-harvest losses and creating jobs for the youth and women in rural areas. To achieve success, a holistic and comprehensive approach in research for development is necessary that considers and addresses production, processing, and marketing challenges simultaneously and involves various stakeholders, such as farmers, development partners, policymakers, the private sector, and the researchers and external donors. The scaling process should be market led, but the level and type of public sector and civil society investment and participation needs careful consideration by donors and national decision makers. It is important to pay attention to the less visible area of fostering relationships and trust among different value chain players.

For improving the productivity of cassava to ensure consistent supply of raw materials to secondary processing units in rural areas, the resource poor smallholder farmers are organized as out grower farmers. The cassava project provides planting materials (except for the local variety), inputs, and know how; the farming community provides land, labour, and information. The project also manages the demonstration trial jointly with the farmers. After planting, at midterm, and at harvest, researchers ask the farmers to evaluate all practices. The "treatments" in the demonstration plots featured farmers' current or local practice, and several best bet options (e.g., cassava monocrop, cassava legume intercrop to demonstrate high yield options), and several treatments where factors such as planting density, fertiliser application, and others are changed or tested. Specifically, the demonstration farms used the following management practices: sole cassava using the varieties TME 419 (erect plant type/growth habit and 30572 (branching plant type) at 1 m x 1 m spacing and different options involving fertiliser (NPK), cassava legume intercropping, spacing with a legume intercrop, and legume type (cowpea, groundnut and soybean etc.).

8. CASSAVA VARIETAL IMPROVEMENT

New high yielding and early maturing cassava varieties that are resistant to local insect pests and diseases; varieties that are rich in nutrients, especially protein and vitamin A, for improving human nutrition; varieties that are high in starch content for industrial uses; and varieties that have a long shelf life are needed to increase cassava farmers' productivity which could lead to a potential increase in income.

8.1. FACTORS AFFECTING FARMERS' CHOICE OF CASSAVA VARIETIES

Understanding farmers' perceptions on improved cassava varieties is crucial to develop new varieties that will suit farmers' different needs in different regions. Farmers' perception of benefits is not only based on superior yields of fresh tuber, but also on harvest duration, quality of processed product for food, labour needs, and the general economics of the improved varieties within local situations. They consider many factors, such as (a) vegetation characteristics of the area with regard to its suitability for growing other crops; (b) population density and the related demand for cassava for food; (c) tribal preferences which restrict cultivation of cassava to poorer farmers who lack land and cash to expand their cassava area with improved varieties; (d) relative competition with cassava of crops like maize, yam, and plantain in each locality; (e) proximity of high density populations of cassava consumers; (f) local presence and capacity of the agencies that can distribute improved planting materials to small scale farmers; and (g) farmers' own perception of overall benefits from improved cassava varieties relative to local varieties. Some farmers often prefer the bitter cassava varieties because they deter pests, animals, and thieves [16]. In addition to understanding farmers' needs, cassava breeders must also collaborate with food and nutrition scientists and technicians to identify and develop new cassava products for local, national and international markets.

8.2. CASSAVA BREEDING IN AFRICA

The International Institute of Tropical Agriculture (IITA) based at Ibadan, Nigeria, is working with the Nigerian Root Crops Research Institute (NRCRI), Umudike, and the HarvestPlus, USA, to develop improved cassava varieties for different parts of West Africa. The three institutions collaborate with and support several African national agricultural research institutes in developing adaptive cassava breeding schemes in their respective countries. In cassava breeding, the good root quality of local cassava landraces like Kakwele and Bamunanika are combined with the high yield and resistance to insect pests and diseases of the IITA bred improved cassava varieties like the TME 14 to develop farmer preferred varieties. Other breeding objectives include developing cassava varieties high in pro-vitamin A; varieties high in starch; and varieties suitable for the production of high quality cassava flour.

Scientists identified four different sources of tolerance to postharvest physiological deterioration (PPD): (a) Walker's Manihot (*M. walkerae*) of southern Texas (USA) and Tamaulipas (Mexico); (b) mutation by gamma rays, which putatively silenced one of the genes involved in PPD genesis; (c) a group of high carotene clones in which the antioxidant properties of carotenoids are postulated to protect the roots from PPD; and (d) a waxy starch (amylose free) mutant tolerant to PPD. These sources were used to develop high yielding cassava varieties that are also tolerant or resistant to PPD, thereby prolonging the shelf life of harvested roots.

The NRCRI has released more than 50 improved cassava varieties during the past 30 years. The two new varieties recently developed are: UMUCASS 42 developed from the IITA TMS-I982132 and UMUCASS 43 developed from the IITA-TMS-I011206. According to pre-varietal release trials conducted between 2008 and 2010, the potential maximum yield of the two varieties was between 49 and 53 t ha^{-1} compared to 10 t ha^{-1} for the local variety. The varieties are also resistant to major pests and diseases that affect cassava in the country including cassava mosaic disease, cassava bacterial blight, cassava anthracnose, cassava mealybug, and cassava green mite. The two varieties have the following distinct qualities:

- Good for high quality cassava flour a sought after trait by researchers for the cassava transformation agenda in Nigeria.
- High dry matter which is positively related to starch and crucial for cassava value chain development.
- High leaf retention which is positively related to drought tolerance and is crucial for cassava production in the drier regions and in mitigating the impact of climate change.
- Moderate levels of beta carotene or pro vitamin A that can address the widespread vitamin A deficiency in cassava consuming populations of Africa.

Since 2011, three vitamin A cassava varieties, UMUCASS 36, UMUCASS 37, and UMUCASS 38, have been released and are being grown (under the Harvest Plus Project) in Nigeria. Other three varieties that have more vitamin A content than the previously released ones have been released in 2015. Overall, there are six vitamin A cassava varieties that are being distributed to farmers in Nigeria and other African countries. These yellow root varieties show a great potential to alleviate the wide spread vitamin A deficiency in the most African populations that consume cassava as their staple food. Farmers' feedback in Nigeria indicate that the yellow roots give good *gari* products and that they are also good for preparing the local cassava dish called *fufu* that looks like custard.

8.3. CASSAVA BREEDING IN ASIA

The International Centre for Tropical Agriculture (CIAT) based at Cali, Colombia, is collaborating with national root crop research institutes in Asia to develop and distribute new high yielding cassava varieties to farmers in different Asian countries. The breeding objectives include high yield and high starch content; varieties resistant/tolerant to local insect pests and diseases; varieties with waxy (sago like) starch content for development of bioplastics; dual purpose varieties for eating and processing; and cold tolerance and suitability to high altitudes. Improved germplasm is the main driver of increased yields of cassava in Asia. New cassava varieties released between 1987 and 2005 were 12 in Thailand, 10 in the Philippines, 9 each in China and Viet Nam, and 1 in Cambodia. Most of the varieties released were high yielding with high dry matter (30 to 40% dry matter) and starch content (85% of the dry matter). In countries like Thailand, public private participation is strong in developing new cassava varieties for food processing and industrial uses.

8.4. REALIZING THE POTENTIAL OF NEW CASSAVA VARIETIES

Improved cassava varieties must be combined with good agronomic management of the crop to enhance farmers' yields. For example, farmers can improve cassava yields by 13% by planting clean, healthy seedlings; 17% by improving soil fertility; 16% by control of insect pests and diseases; 11% by prevention of soil erosion; and 9% by timely weeding. In addition, breeders can contribute to an intrinsic increase of 19% in potential yield of cassava varieties. With improved cassava varieties and improved crop management, farmers can attain a yield level of 30 to 40 t ha^{-1}, compared to the current national average yield of 12 to 14 t ha^{-1}.

9. CASSAVA SEED VALUE CHAIN: PROVIDING HEALTHY PLANTING MATERIALS TO FARMERS

For cassava, the word seed refers to the cassava stems (FIG. 6) that are cut into 25 cm pieces for planting a new crop in each growing season. However, the use of planting material from a previous generation to establish the next provides an easy way for disease causing pathogens, particularly viruses, to pass directly from one plant generation to another. So, while the vegetative propagation offers convenience, vegetative propagated crops are often more widely affected by pathogens than those planted in the form of true seeds. Therefore, providing healthy, disease free planting materials is the first step in realizing the potential impacts of improved cassava varieties on farmers' productivity, income and livelihood.

FIG. 6. A farmer carrying cassava stems to plant in a new field (Photo by L. Kumar, IITA).

Earlier, the distribution of planting materials of new varieties was handled through the 'Growth Enhancement Scheme' in Nigeria. Between 2012 and 2013, the NRCRI has reached 300 000 farmers with the vitamin A cassava varieties. Each farming household receives cuttings of at least two varieties out of the three. If a farmer plants one 25 cm stick of an improved variety this year, he/she can get at least a minimum of eight sticks from it next year. Thus, farmers themselves can multiply the new planting materials several fold each year and use them for planting in the own fields or sell them to other farmers in their neighbourhood.

Despite some isolated efforts as mentioned above, the cassava seed system is a big constraint to farmers and industries in getting the varieties they need. No one is currently able to go to designated spots and purchase cassava stem cuttings if he/she desires to establish a new business in cassava stem cuttings of improved varieties. To address this constraint, a new four year project (2015–2019) titled 'Building a Sustainable, Integrated Seed System for Cassava in Nigeria' (BASICS) funded by the Bill & Melinda Gates Foundation and led by the CGIAR Research Program on Roots, Tubers and Bananas (RTB) has been initiated at IITA in 2015 to develop a commercially sustainable cassava seed value chain in Nigeria. Good quality, disease free stem cuttings would be provided to farmers by vibrant and profitable village seed entrepreneurs and basic seed production linked to processors. The seed system starts from the development of healthy plantlets of new varieties in tissue culture laboratory to the production of breeder seeds which will then be multiplied to produce foundation seeds and finally to be multiplied by commercial seed producers for farmers to get good quality seeds of their preferred varieties. These seed businesses will provide quality, certified seeds of the right varieties leading to adoption of new varieties to improve productivity and food security, increase incomes of both cassava growers and seed entrepreneurs, and enhance gender equity. By 2019, smallholder growers could buy high quality stems of their preferred varieties and plant them using improved agronomic practices. It is predicted that, as a result, cassava root yields would increase by at least 40% and farmers would potentially have more secure markets for expanded production.

The Quality Management Protocol (QMP) has been developed to multiply disease free cassava planting materials and distribute them to farmers. The key components of the QMP are as follows: Primary (centralised) multiplication sites multiplying the virus tested cassava plantlets derived from tissue culture and managed by researchers or qualified seed producers, secondary, and tertiary multiplication sites (usually in farmers' fields) are all assessed, at least once in a year, for quality parameters, primarily in terms of disease and pest incidence and quality of planting materials. The QMP standards for cassava mosaic disease and cassava brown streak disease incidences ascertained by diagnostic tests are <10% for primary and secondary sites and <20% for tertiary sites in endemic areas. In addition, the management of cassava diseases could be greatly enhanced by raising awareness among growers about the importance of establishing the next crop with healthy planting material.

With this program, healthy and disease-free planting materials have been provided to more than half a million beneficiaries in six countries and it provides an important model for other current and future cassava development programs. For successful replication of the QMP based cassava seed systems, basic capacity needs must be strengthened in most countries. Key elements of this include the laboratory and human capacity for virus indexing, as well as the knowledge of QMP and the capacity of the national plant quarantine organization to monitor cassava seed systems.

Research is ongoing to develop new cassava propagation methods like micro sticks and petiole based propagation. Such efforts will help produce disease free planting materials of improved cassava varieties.

10. LAND CONFIGURATION – SHAPING THE LANDSCAPES FOR PROTECTING SOIL AND WATER RESOURCES

Most farmers use flat land to plant cassava, while others facing scarcity of land are forced to cultivate sloping lands for growing cassava and other crops. When the widely spaced cassava is planted on sloping lands without any intercropping or contour planting, in which case the risk of soil erosion increases several folds during periods of heavy rains (FIG. 5). This is because the bare soil between the widely spaced cassava plants is exposed to direct rainfall, causing runoff and soil erosion, during the early growth period (2–3 months after planting). The steeper the slope, the greater is the soil loss from water erosion.

10.1. ON FLAT LOWLANDS AND UPLANDS

- Formation of ridges and furrows or raised beds and furrows to facilitate drainage of excess rainwater in poorly drained areas and to use rainfall or irrigation water efficiently.
- Tied ridges to collect rainwater in semi-arid and drought prone areas.
- Intercropping cassava with fast ground covering, short term crops like peanut, cowpea, or a bean that protects the soil surface, provides a quick harvest and income, and helps control weeds.
- Mulching with crop residues or grass clippings on the soil surface to protect the soil from direct raindrop impact, thereby greatly improving rainwater infiltration and reducing soil erosion [17].
- The addition of plant ash or biochar instead of expensive lime to reduce soil acidity – a common problem in Africa.
- Proper soil fertility management and increasing soil organic matter contents through implementation of integrated soil fertility management by applying both organic and fertiliser nutrient sources as per local availability, their relative prices, and farmers' affordability.

10.2. ON SLOPING LANDS ON HILL SIDES (SLOPING LAND AGRICULTURAL TECHNOLOGIES, SLAT)

- Reforestation and regeneration of vegetation in upper watersheds of tropical highlands and mid altitude areas to reduce soil erosion and to improve water supply through the restoration of local springs and streams.
- Intercropping or mixed cropping of cassava with grain legumes and mulching of the soil surface with crop residues or grass clippings to reduce soil erosion, suppress weed growth, and enhance infiltration of rainwater.
- Growing cassava crops between rows of perennials including shrubs and trees (agroforestry) or between contour planted live hedges, forage grass strips that can be fed to farm animals, or constructed stone barriers or trenches on sloping hill sides [17,18].

It is important to note that farmers' adoption of soil and water conservation practices, especially on sloping lands, is weak due to high labour demand to maintain the anti-erosion structures. To improve adoption of anti-erosion measures, we need appropriate changes in rural infrastructure and smart incentives and financial support to farmers adopting soil and water conservation measures.

11. LAND PREPARATION METHODS FOR CASSAVA CULTIVATION

Timely land preparation and planting of the cassava cuttings at right spacing and at right depth will help establish a uniform crop stand in the field; it will also help farmers to take full advantage of the growing season and thus obtain high yields in rainfed cassava farms. Appropriate mechanization will help farmers carry out all farming operations, including efficient land preparation in a timely manner.

Fields can be prepared for planting cassava in five different ways: (a) Slash and burn method; (b) conventional tillage (CT); (c) forming ridges and furrows (RF) after CT; (d) forming mounds after CT; and (e) reduced or zero tillage (RT or ZT).

11.1. SLASH AND BURN METHOD OF LAND PREPARATION (SHIFTING CULTIVATION)

Subsistence farmers living in remote uplands of developing Asia and Africa practice slash and burn method of land preparation for planting maize, cassava, and other crops. In traditional slash and burn method, the bush is cleared from the land often with the help of a fire, the land is then ploughed once or twice, and seeds of maize and other grain crops are planted for 1 to 2 years to exploit the fertility of virgin soils, and then cassava is planted on depleted soils as the last crop of the cultivation cycle (FIG.7). This is because cassava is capable of growing and providing some root yield even when soil fertility is low. The second reason why cassava is planted as the last crop in shifting cultivation sequence is that it does not have a fixed harvest period. It can be stored in the soil for up to two years and harvested when other food has run out, often doubling in yield during that time. If soils are not tilled prior to planting and the crop remains in the ground for two years, the soil erosion hazard from planting on sloping lands is less than from an annual crop like maize that is commonly tilled before planting each year [17]. After cassava is harvested, the land is left fallow for the regeneration of vegetation and restoration of soil fertility over a period of 15 to 18 years. This long fallow shifting cultivations was sustainable due to effective regeneration of natural vegetation and soil fertility during the long fallow period. However, with increasing population pressure on land, farmers were forced to reduce the fallow period to 3–4 years between the cropping cycles. Such a short fallow shifting cultivation resulted in increased soil erosion, nutrient depleted and dried out soils, decimated soil organic matter, reduced soil microbial diversity, and an increase in infestation by weeds. As a result, the yields of crops including that of cassava have steadily declined in Asian and African uplands.

FIG. 7. Slash and burn method of land preparation for planting maize and other grain crops for 1 to 2 years and cassava as the last crop of the cropping phase before the land is left fallow for a long period.

11.2. CONVENTIONAL TILLAGE

Conventional tillage involves one primary tillage (ploughing) followed by 1–2 secondary tillage (harrowing) and levelling (if needed) (FIG. 8a,b). The steps involved in CT are:

1. Manual labour, an animal drawn plough, a small power tiller, or a four–wheel motorized tractor, can be used for primary tillage. Plough the field when the soil is moist and friable.
2. Spread out residues from the previous crop and apply organic manure or compost and then incorporate them into the soil during the first ploughing.
3. Wait for the first rain, or irrigate the field (if possible) and allow 15 days for weed seeds to germinate and for organic matter to decompose in moist soil.
4. Apply (broadcast uniformly) a phosphorus fertiliser, and also make the first application of a potassium fertiliser prior to the secondary tillage.
5. Plough for 2nd time to uproot the germinated weeds, then harrow and finally level the soil under dry condition.

11.3. RIDGES AND FURROWS (RF) METHOD OF LAND PREPARATION

Here the land is ploughed, harrowed, levelled and then ridges and furrows are formed with the help of furrow openers (FIG. 8 a, b, d, e). The ridges are formed between furrows are 75 to 100 cm wide at their base. The furrows are made gently sloping along the natural slope of the field to help drain the water, if necessary, during heavy rains. The ridges are reshaped once every year by taking the excess soil from furrows and placing it uniformly on top of the ridges with the help of furrow openers attached to a tractor. Cassava stem cuttings are planted on ridges with a spacing of 50 to 75 cm between seed holes on ridges.

11.4. FORMING MOUNDS

After ploughing and harrowing mounds are formed manually for planting cassava (FIG. 8f), the mounds are 50–60 cm tall and 80–100 cm diameter at the base. The spacing between mounds will be 100 – 120 cm on either side.

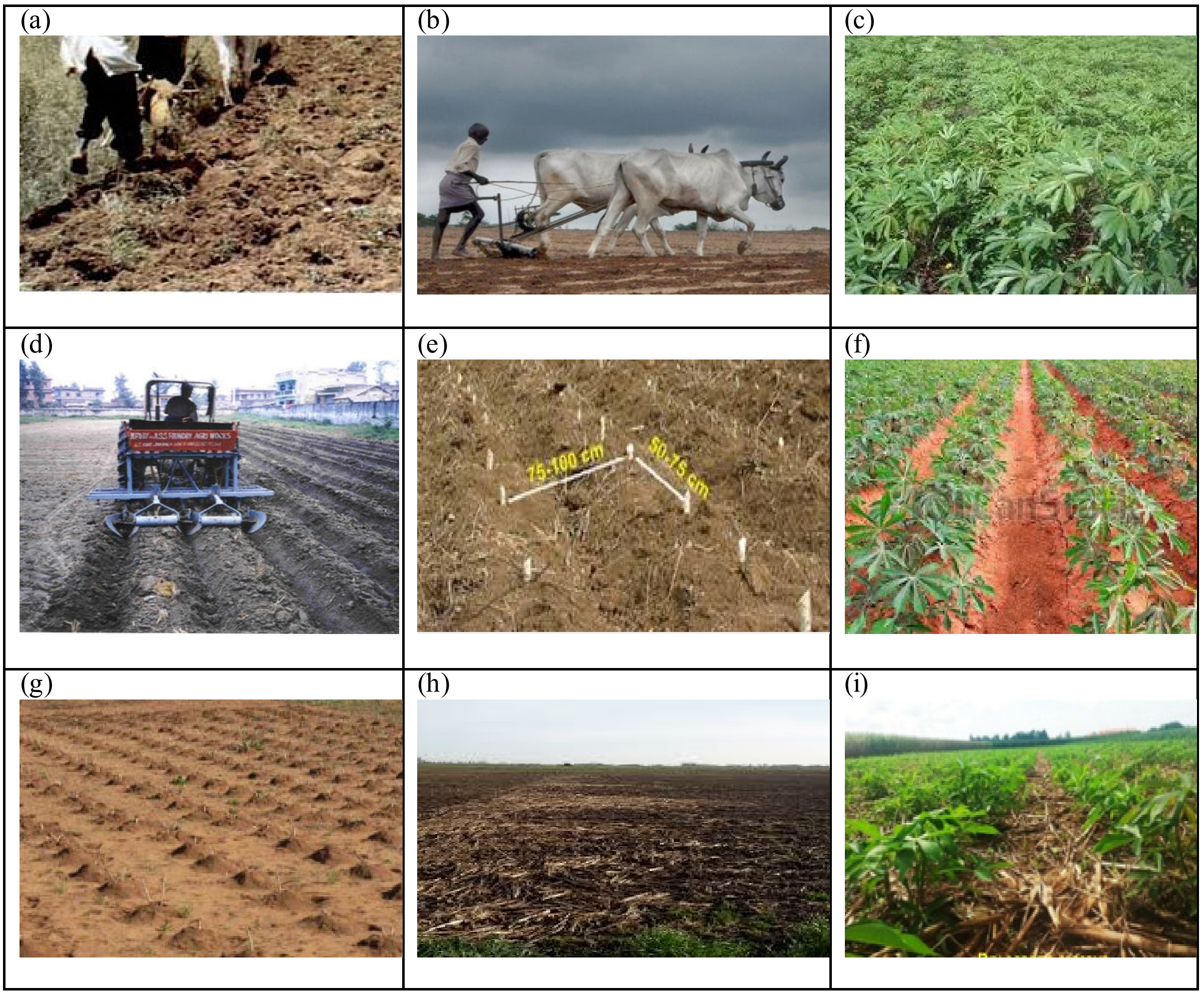

FIG. 8. Methods of land preparation and planting of cassava as a monocrop on flat land, on ridges, and on zero till fields. (a) Preparing the land flat primary tillage by animal (India), (b) Preparing the land flat harrowing with bullocks in India, (c) Cassava monocrop planted on flat land, (d) Formation of ridges and furrows (Nepal), (e) Planting of stem cuttings (spacing of 75–100 cm between ridges; 50–75 cm between planting holes within ridge), (f) Cassava mono crop planted on ridges, (g) Formation of mounds for planting cassava, (h) Zero till field with residues on soil surface, and (i) Cassava planted on zero till plots with mulching of maize residues.

11.5. REDUCED/ZERO TILLAGE OPTIONS

Reduced tillage (RT) or zero tillage (ZT) methods of land preparation and ground cover management with crop residues are being trialled to determine whether soil health, crop yields and crop water use efficiency can be improved in rainfed upland cassava based cropping systems. Both RT and ZT methods and crop residue management (FIG. 8 h,i) are the two key components of conservation agriculture (CA), the third one being crop diversification through crop rotation and intercropping or mixed cropping of cassava with grain legumes. Upland farmers practice RT or ZT (especially on steep slopes where machines cannot be used to prepare the land).

In shifting cultivation in Asia and Africa, cassava stem cuttings are planted as the last crop of the cropping cycle on a land covered with residues of the previous crop. Surface mulching with crop residues will help infiltrate rainwater into the soil, conserve soil organic matter and soil moisture, and improve water use efficiency by crops. The cassava crop that remains on the ground for almost two years will protect the soil against erosion on sloping lands through its live vegetation cover over the soil till it is harvested [17].

On steep slopes of northern Laos and southern China, the bush vegetation is cleared with a machete, and then the dried debris is burnt. Farmers make only holes for planting cassava stem cuttings horizontally. This is a form of reduced tillage that decreases the risk of soil erosion.

12. CASSAVA CROP ESTABLISHMENT

Proper establishment of the crops is critical for successful crop production. The aim is to get a fast and uniform sprouting of the planted stem cuttings and a vigorous early growth of the young cassava plants – all in order to develop an early and full canopy over the soil to suppress weeds and to use all resources efficiently and evenly over the entire field. Once a uniform crop stand is achieved, further management of the crop becomes easier.

12.1. PREPARING THE STEM CUTTINGS

Stem cuttings are used for planting a new crop of cassava every season. The stems for planting are normally cut when the mother plant is 8–12 months old. Cuttings taken from the lower and middle parts of the stem have higher germination (sprouting) rates than those derived from the upper part of the stem and 15–25 cm long cuttings have higher percentage of germination than shorter cuttings (5–10 cm length). For most cassava varieties, the cut stems can be stored vertically in the shade for 1–2 months before planting, without the risk of reducing the germination percentage below 80%; other sensitive varieties lose their germination capacity after 3–4 weeks of storage.

12.2. SPACING AND PLANT POPULATION

Cassava stem cuttings are planted on a conventionally tilled flat land, on ridges separated by furrows, on mounds, or on zero till fields with crop residues covering the soil surface (FIG. 8). The planting density for cassava varies from 10 000 to 25 000 plants per hectare depending on the fertility level of soil and the branching habit of the varieties chosen for planting. The general spacing is 75 to 100 cm between rows or ridges and 50 to 75 cm between planting holes within rows or ridges (FIG. 8) for a mono crop cassava. In this case, the planting density for a monocrop cassava ranges between 13 333 plants per hectare (100 cm x 75 cm spacing) in fertile soils to 26 666 plants per hectare (75 cm x 50 cm spacing) in poor or infertile soils. For a monocrop cassava, higher planting density will also help develop the canopy cover over the soil faster than a crop planted at a lower density.

A wider spacing of up to 200 cm between rows or ridges is used when cassava is intercropped with 1 to 3 rows of fast growing legumes or a cereal crop like maize or millets. Here, the spacing between cassava plants within each row or ridge is reduced to 50 cm to have a decent cassava population density.

Cassava root yields will not be reduced significantly when the established plant stand is 70–80% of the targeted plant population. This is because the plants surrounded by open spaces will grow more vigorously and produce higher yields per plant, thus compensating for the lower plant stand. If possible, missing plants should be replaced within 2–3 weeks from the original date of planting.

12.3. METHODS OF PLANTING

In tilled, loose soil, the stem cutting can be planted vertically or in a slanted position by pushing the lower part of the cutting 5–10 cm deep into the soil. Care should be taken that the eyes or buds on the stem cuttings face upward. Alternatively, stem cuttings can be planted horizontally at 5–7 cm depth by digging individual holes or by making a long furrow, placing the cuttings in the hole or in the furrow at required spacing, and covering them with soil. Horizontal planting is common in heavy clay soils or with zero or minimum tillage methods of land preparation.

13. WATER CONSERVATION AND MANAGEMENT

Cassava is a highly resilient crop that will grow on poor soils and in areas with variable rainfall, but at the same time, it is the most efficient user of available water (soil moisture) and most nutrients. This is the reason why cassava is consigned as a poor man's crop cultivated on marginal soils with variable moisture where no other crops will grow. However, an adequate rainfall and or irrigation water is needed to produce high yields in intensive cassava farming systems. Cassava yields are drastically reduced and the quality of roots is affected adversely when the crop faces extreme droughts or waterlogged conditions.

13.1. METHODS OF IRRIGATION – WATER SAVING IRRIGATION TECHNOLOGIES

Flood irrigation: On flat land, small basins are formed after planting the crop and irrigation water is let into the basins to soak the soil thoroughly (FIG.9a), once every 10 to 15 days, depending on local weather.

Furrow irrigation: Where cassava is planted on ridges separated by furrows, water is released into the furrows and allowed to seep laterally into the ridges (FIG.9b). This is more efficient in water use than flood irrigation.

Drip irrigation: Also known as the "trickle" irrigation, the drip irrigation encompasses all approaches that involve applying the irrigation water directly on to the crop's root zone (FIG.9c). Under this system, water moves through a network of narrow plastic pipes under low pressure and is delivered to the root zone of the cassava or other crops, drop by drop through drippers. The drip irrigation system thus helps in the optimization of water resources in water scarce areas while increasing crop yields by 20 to 90%. The advantages include a 50–60% saving of water compared to flow or flood irrigation, an efficient use of fertilisers when water soluble fertilisers are dissolved in irrigation water and applied to crops (fertigation). In addition, energy costs for irrigation are reduced. The drip irrigation also reduces the salinity hazard to crops planted in saline soils by diluting the salt content in the crop root zone, and/or moving the salts below the root zone. Weed growth is less in drip irrigated plots because the water is supplied only to crops' root system. The limitations of drip irrigation system are its high initial cost which small and marginal farmers cannot afford without a bank loan; the need for a technical knowledge and skill to install and maintain the drip system; blocking of drippers by evaporated salt and or algal/fungal growth, especially when poor quality water is used. Other problems include the supply of poor quality irrigation pipe, drippers, connectors, etc. and the often limited or poor technical support and after sales service provided by local dealers. Finally, the improper disposal of damaged plastic pipes/tubing (used in mains, sub mains, and laterals) creates litter and pollution, especially if burned at low temperature.

FIG. 9. Different methods of irrigation for cassava fields. (a) flood irrigation of cassava, (b) furrow irrigation and (c) drip irrigation of cassava.

13.2. MANAGING RAINFALL FOR RAIN FED CASSAVA CROPS – RAINWATER HARVESTING AND FARM PONDS

Decentralised rainwater harvesting structures like farm ponds (FIG.10), small community reservoirs or earthern check dams across water courses should be built in both drought and flood prone rainfed lowlands and uplands. These water holding structures can help mitigate both drought and flooding impacts on crops and people by collecting and storing rainwater from peak floods and using it for supplemental irrigation of crops and for provding water for animals and people during periods of drought [19]. Water storage in farm ponds and nearby water bodies will also help to recharge groundwater, and revive small streams and dried out borewells on nearby land areas, thereby increasing water availability in rural (farming) areas. In India, rainwater harvesting structures, which are refilled during monsoons, reduce runoff by 40% and soil losses by 50%, and increase cropping intensity by 180% [20, 21]. The farm pond schemes with partial support of state and central governments are active in many states of India and they can be extended to Africa as well.

FIG. 10. Farmers dig farm ponds at strategic locations in their farms to harvest rainwater which can mitigate floods and provide water for life saving irrigation of crops and quenching the thirst of animals and people during periods of drought [19].

14. SOIL FERTILITY AND NUTRIENT MANAGEMENT OF CASSAVA CROPS

Cassava can be a hardy, flexible crop that can grow fairly well in most soils including marginal ones. However, for sustaining high cassava yields over long term, it is important to replenish the soil with all the nutrients removed by the cassava crop in each season. For example, for each ton of dry weight equivalent of cassava root yield, the crop exports from soil 4.1 kg of N, 1 kg of P, and 8.3 kg of K. Some of the nutrients removed by the crop are returned to the soil in the form of leaf litter and other residues of the cassava plants after the harvest. The only point that needs emphasis is that cassava requires twice the amount of K as compared to N uptake and that P requirement is very low. Another fact to remember is that the crop uptake of nutrients increases faster than the dry matter accumulation in the roots, in other words, higher the root yield, higher is the concentration of nutrients in the roots [22]. The nutrient removal from the soil is quite large when root yields are high. For example, for a fresh root yield of 35.7 t ha^{-1} (13.52 t ha^{-1} of dry weight of roots), the crop will export from the soil 55 kg ha^{-1} of N, 13.2 kg ha^{-1} of P and 112 kg ha^{-1} of K. As part of the nutrients contained in the crop is returned to the soil, actual nutrient removal of nutrients from the soil is less than that calculated based on root yield and nutrient concentration. For an average root yield of 15 t ha^{-1}, the crop will take up 30 kg N, 8 kg P_2O_5, and 24 kg K_2O. Thus, the ratio of nutrient requirement for cassava will be 3 N – 1 P_2O_5 – 3 K_2O. Therefore, in an NPK compound fertiliser to be developed for cassava, we should have three times N and K for every unit of P. In most soils, cassava responds to K>N>P, unless the soil is extremely deficient in N. Potassium application is critical not only to increase crop yields, but also to increase starch content in roots.

14.1. SITE SPECIFIC NUTRIENT MANAGEMENT (SSNM)

Fertilisers alone supply only selected nutrients (N, P, K), therefore continuous applications of fertilisers alone will deplete nutrients that are not supplied through fertilisers, causing multiple nutrients deficiency. To combat this problem, site specific nutrient management (SSNM) is needed. In SSNM, it is advised to apply all organic residues/manures/wastes available from farms and supplement it with fertilisers to attain the targeted yields. Organic manures, particularly animal manures, will provide secondary (Ca, Mg, S) and micronutrients (Cu, Fe, Mn, Zn), while fertilisers will supply major nutrients (N, P, K) to cassava and other crops. In fertiliser trials, it was found that cassava root yields were the highest either with a well-balanced application of NPK fertilisers or combined application moderate amount (5 t ha^{-1}) animal manure supplemented by moderate levels of N and K fertilisers (Table 2) [23]. Similar results were also reported by for two long term experiments conducted at the Central Tuber Crops Research Institute (CTCRI), Kerala, India.

TABLE 2. RESPONSE OF CASSAVA TO INCREASING APPLICATION OF FARM YARD MANURE (FYM) WITH AND WITHOUT 80 N 80 K_2O KG HA^{-1} FERTILISERS AT THAI NGUYEN UNIVERSITY OF AGRICULTURE AND FORESTRY, THAI NGUYEN PROVINCE, VIETNAM, 2001 (2^{ND} YEAR OF LONG TERM TRIAL).

Fertiliser treatments	Fresh root yield ($t\ ha^{-1}$)	Plant height at 8 MAP (cm)	Harvest Index (HI)
Control	3.25	87.1	0.39
FYM: 5 t ha^{-1}	7.79	116.6	0.49
FYM: 10 t ha^{-1}	10.02	133.9	0.52
FYM: 15 t ha^{-1}	13.11	151.8	0.52
80 N 80 K_2O kg $ha^{-}1$ only	15.47	154.5	0.50
80 N 80 K_2O kg ha^{-1} + FYM: 5 t ha^{-1}	17.98	180.0	0.48
80 N 80 K_2O kg ha^{-1} + FYM: 10 t ha^{-1}	18.70	188.3	0.49
80 N 80 K_2O kg ha^{-1} + FYM: 15 t ha^{-1}	18.50	196.6	0.48

NB: MAP = months after planting; t = tons; FYM = farm yard manure (pig manure)

Trials on the best time of fertiliser application indicate that the best responses are obtained when all the fertilisers are applied at the time of planting. Alternatively, all the P and half of the N and K are applied at planting and the remaining N and K applied 2–3 months after planting. The fertiliser can be band-applied near the crop rows or spot-applied 5–10 cm from the base of the plants.

In problems soils, before applying fertilisers, soil amendments such as lime, gypsum and animal/organic manure have to be applied to correct specific problems like soil acidity and Al toxicity [24], salinity, and very low level of soil organic matter respectively.

14.2. THE CASE OF INTEGRATED SOIL FERTILITY MANAGEMENT (ISFM) IN AFRICA

The SSNM principles have been incorporated into a program called Integrated Soil Fertility Management (ISFM) that is extensively promoted throughout Africa. The progressive ISFM interventions are shown in FIG. 11. The three major steps involved in implementing the IFSM are discussed briefly below.

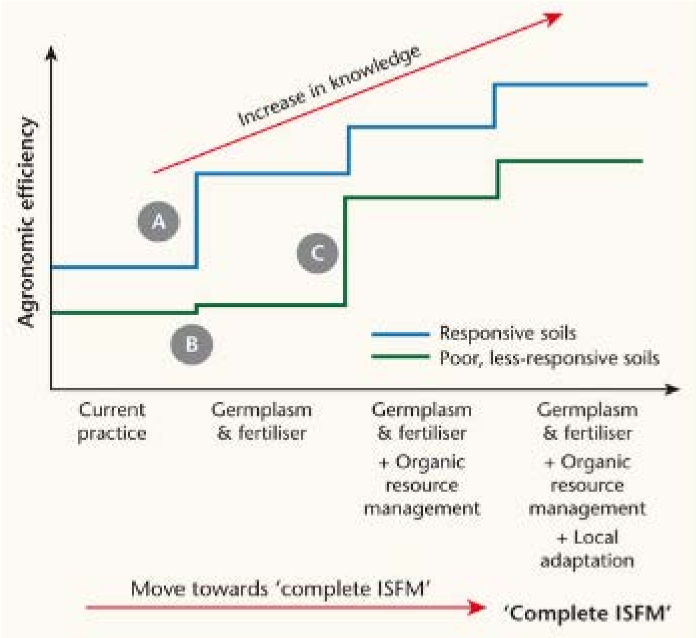

FIG. 11. Progressive interventions involved in integrated soil fertility management (ISFM).

Step 1: Intensification of crop productivity through improved varieties and healthy seed systems [25, 26] combined with judicious use of fertilisers. Enhancing fertiliser use efficiency through: i) incorporation of surface applied urea into the soil to reduce N volatilization losses, ii) increasing P availability to plants by banding of P fertilisers on soils that strongly adsorb P, and iii) point placement or banding of inorganic fertiliser inputs (FIG.12) that increases nutrients uptake and reduces fertiliser requirements.

FIG. 12. Manual band placement of fertiliser near seed rows on ridges [Source: International Institute of Tropical Agriculture (IITA), Nigeria.

Step 2: Organic residues (FIG.13a) are a valuable source of organic matter inputs to soils and nutrients for plant growth. Organic resource management is designed to neutralise soil acidity and to replenish K, Ca and Mg that are exported from soils in harvested produce [27]. In addition, rotation and or intercropping of cassava with the fast ground covering, short term grain legumes like beans, soybeans, cowpea, and groundnut can enrich the soil with biological N fixation, protects the soil surface against erosion, helps control weeds, and provides a quick harvest and income to farmers [17]; they also improve the overall productivity and fertiliser use efficiency of cassava based cropping systems [28]. In no till farming systems, organic matter accumulated in soils prevents nutrient tie up by clay minerals and increases microbial breakdown of organic residues, thereby releasing nutrients for plant uptake.

FIG. 13a. Crop residues provide valuable organic matter and plant nutrients to improve crop productivity and soil quality (Source: M.Zaman).

In poor sandy soils of southern Ivory Coast, the ISFM based cassava cowpea intercropping systems outperformed the local cassava monocrop cultivation system. The average cassava yield was 14.5 and 6.5 t ha^{-1} and 12.6 and 5.7 t ha^{-1} for the ISFM and traditional systems, in Dabou and Bingerville, respectively. Taking into account the limited farmer's resource endowment and poor soil fertility, ISFM is a crucial component for sustainable intensification of cassava production and poverty alleviation in southern Ivory Coast [29].

Step 3: Tackling specific limitations to crop production, for example, by the application of lime, ash or biochar to correct soil acidity; soil testing and addition of missing nutrients to promote balanced nutrient use; tied ridging, formation of contour barriers, stone row alignment, and growing crops in zai pits or basins to enhance water harvesting in drought prone areas; and or targeted use of herbicides or pesticides to control weeds, insect pests and diseases.

14.3. BENEFITS OF ADOPTING ISFM IN AFRICA

Farmers reap many benefits from the SSNM based IFSM as shown below:

14.3.1. Economic and livelihood benefits

ISFM reduces fertiliser costs and increases net profit to farmers. The contributions of ISFM practices to improving the livelihood of farmers can be evaluated using indicators such as nutrition, health and gender at household and societal levels. The practice of ISFM improves family nutrition due to higher intake of calories and proteins by family members.

14.3.2. Impact of ISFM on resilience of crop production to climate change

Benefits of practicing ISFM on the resilience of crop production to climate change can be assessed by indicators related to the stability of production, water use efficiency and soil conservation at farm and landscape levels. Improved management of organic resources increases soil organic matter content which in turn improves retention of water and nutrients by soils, reduce soil erosion and evaporation of soil moisture due to surface mulching, and increases fertiliser use efficiency [17]. Crop diversification through mixing of annual and perennial crops can also contribute to addressing climate impacts on agricultural production and food security [30]. Practices such as tied ridging, formation of contour barriers, stone row alignment, and growing crops in zai pits or basins that enhance water harvesting and prevent soil erosion [31] improve crop growth and development in drought prone areas. Intensification of crop productivity by practicing ISFM enhances the availability of fodder for rearing livestock which improves family food security and cash flow, thereby strengthening the resilience of smallholder farming households to climate change impacts.

14.3.3. Impact of ISFM on greenhouse gas (GHG) emissions

The impact of ISFM on GHG emissions from soils can be evaluated by monitoring and measuring agronomic efficiency of fertilisers, as well as build-up of soil carbon stocks at farm and landscape level in combination with default GHG emission factors. Adoption of ISFM mitigates GHG emissions by reducing losses of N fertilisers and soil carbon to the atmosphere. As shown earlier, micro dosing of N fertilisers through application to individual planting holes enhances N use by crops [32]. ISFM interventions on organic inputs increase soil carbon stocks which in turn improve the water and nutrients retention capacity of soils and at the same time enhances fertiliser N uptake by crops [33]. In cassava grain legume rotation systems, significant N benefits were derived from cowpea and groundnut [17, 29]. Substituting an input of 10 kg urea-N ha^{-1} directly mitigates emissions of 20 kg CO_2 equivalent for manufacturing the fertiliser [34]. A reduction of fertiliser inputs by 10 kg N ha^{-1} is by default accounted to lessen N_2O emissions from soils in equivalence of 60 kg CO_2 eq per hectare [35].

Thus, by combining organic and inorganic N sources, smallholder farmers can mitigate agricultural derived GHG emissions without compromising on crop productivity. For example, under both temperate China and tropical Zimbabwe conditions, combined application of organic residues and N fertilisers resulted in lower N_2O emissions compared to inorganic fertilisers which had higher total and yield scale N_2O emissions [36].

FIG. 13b. Crop residues provide valuable organic matter and plant nutrients to improve crop productivity and soil quality (Source: IPNI). Cassava – A resilient crop of last resort for food security and a competitive industrial crop for commercial farmers.

15. WEEDS AND THEIR MANAGEMENT

Weeds are undesirable plants that affect the growth and development of any plant including cassava. Weeds compete with cassava plants for space, water, nutrients and light, thereby inhibiting crop growth and reducing crop yields. Weeds can also serve as alternate hosts for insect pests, pathogens and vectors of diseases; and provide a safe habitat for rats which often attack cassava roots. Major reasons for weed competition are: planting the cassava stem cuttings too many days after land preparation; planting cassava at wider spacing thus providing an opportunity for weeds to infest in the field; late weeding and allowing weeds to flower and set seeds; poor manual weed control; ineffective herbicide application; allelopathic weeds; increasing weed density due to continuous monocropping of cassava after cassava; increasing weed infestation due to depletion of soil fertility; and the problem weed species including the herbicide tolerant ones that cannot be controlled by current methods.

Both grasses (e.g., spear grass) and sedges are commonly found in cassava farms. The growing weed problems limit the productivity of cassava, and negatively impact the farming families. Weeding takes 50 to 80% of the total labour budget of cassava growers. Up to 200–500 hours per hectare of labour, mostly of women and children, are required to prevent economic cassava root losses. Women contribute more than 90% of the hand weeding labour while 69% of farm children between the ages of 5–14 are forced to leave school and engaged in weeding in Nigeria. This burden compromises their education. Unless weed control is improved, Nigerian farmers will not produce optimal cassava yields, since farm families cannot plant more area than they can weed.

15.1. INTEGRATED WEED MANAGEMENT

Cassava is a poor competitor with weeds due to its slow early growth and delayed canopy cover. Therefore, an effective weed control is critical during the early growth period (up to 3 months after planting) to prevent yield losses due to weed competition. Farmers shall adopt integrated weed management strategies so that they have less need to resort to herbicides. Integrated weed management uses a combination of cultural, manual, mechanical and/or chemical weed control methods.

15.1.1. Agronomic/cultural methods

Agronomic and cultural control methods such as minimum or zero tillage, maintaining soil cover, practicing crop rotation and intercropping, and preventing weed seeding are all effective measures for reducing weed pressure on crop production. These cultural weed control methods are generally ecologically sound because they minimise or avoid the use of chemical herbicides; they are also easy to use and often cost effective. They adopt the principle of 'prevention is better than cure' as discussed below.

- Good land preparation and leveling to reduce emergence of weeds.
- Selection of early branching cassava varieties that suppress weeds and use of good quality stem cuttings as well as planting cassava in high density and better crop nutrition would control early weed growth.
- Breaking the continuous moncrop cassava with rotation of crops that will help to break weed and insect pest cycles and thus minimise weed infestation. Similarly intercopping of cassava with fast growing grain legumes like clowpea, groundnut, soybeans, and beans will also help cover the ground early and reduce the weed pressure on cassava crops.
- Mulching cassava with fields plant residues (crop residues; leaf litter from nearby trees, alley crops, and leguminous plants; rice husks, etc.) to block out light to the soil and make it difficult for weeds to grow.
- Growing weed suppressing cover crops (which also have substantial soil benefits, e.g., legumes).
- Applying N fertiliser just after weeding will minimise competition from weeds.
- Reducing the weed "seed bank" in the soil by killing weeds in fallow fields before they flower and set seed is especially useful (remember the phrase – 'one year seeds, seven years weeds').

Although planting cassava in high density and better crop nutrition would suppress weed growth, judicious use of herbicides may be needed for effective control of weeds, especially in zero till fields.

15.1.2. Manual (hand) weeding

Many resource poor farmers remove weeds by hand, often with the help of a hoe. Although it provides employment for landless rural people, the drudgery and a growing scarcity of labour are making it less likely that manual weeding will be performed, in the future, in a timely fashion. Even so, a brief discussion of how best to hand weed is given below:

- Start hand weeding when weeds are large enough to grasp, i.e. about 30 to 45 days after the sprouting of cassava stem cuttings.

- Repeat the weeding once or twice more or as and when needed. Once the canopy is fully developed, cassava plants will shade out the weeds.
- Never allow weeds to flower and set seeds in the cassava field. Weed the field before applying N and other fertilisers so as to minimise nutrient uptake by weeds.

15.1.3. Mechanical weeding

Mechanical weeding involves inter row cultivation to uproot and bury young weeds. It is a non-chemical, ecologically sound method and is more efficient and less labour intensive than hand weeding. The soil stirring that occurs in mechanical weeding can increase root and shoot growth in cassava crops. However, mechanical weeding can be used only for crops planted in rows.

15.1.4. Chemical weed control – Herbicides use

Herbicides can be used before planting or just after seeding (e.g. pre-emergence herbicides), or after the sprouting of the cassava stem cuttings (post emergence herbicides) in order to kill specific weed species. Recommended pre-emergence herbicides are fluometuron, diuron and alachlor, and post emergence herbicide Paraquat, as a complement to hand/hoe weeding.

Herbicide application requires less labour (0.5-person day per hectare for one application) and is cost efficient. If chosen properly and applied correctly, herbicides can give an effective control of weeds. However, application of the same herbicide, season after season can sometimes lead to the development of herbicide resistance. Use the following steps to apply herbicides correctly:

- Select an appropriate herbicide for the weeds to be controlled, and the stage of the cassava and the associated crops. Be certain to use the recommended rate of application.
- Some herbicides are designed to control the weeds before they emerge (i.e., pre emergence), while others are only effective after the weeds have emerged (post emergence).
- Always read and follow the instructions on the product label.
- Mix the recommended amount of herbicide with required amount of clean water in a suitable sprayer, one which has an appropriate spray nozzle.
- Uniformly apply the herbicide + water mix across the field: maintaining a steady pressure by pumping and a steady walking speed. This will ensure a uniform spray application action.
- Spray the herbicide product from a height of around 50 cm above the target plants.
- Spray ideally only on calm days, or if there is a minor wind, spray perpendicular to the wind, so that herbicide spray is blown away from the person applying the spray.
- Rotate the herbicide ‘types’, insofar as possible, in subsequent years to help prevent the development of herbicide resistant weeds.

16. INSECT PESTS AND DISEASES AND THEIR MANAGEMENT: INTEGRATED PEST MANAGEMENT (IPM)

Biotic constraints include insect pests and diseases that attack the cassava crops and lead to lower yield.

16.1. KEY INSECT PESTS OF CASSAVA

The common insect pests that affect cassava crops in Africa and Asia are: cassava green mites, cassava mealy bugs and whiteflies (FIG.14). Grasshopper attack is more widespread in Africa than in Asia, while attack by white grubs is more common in Asia than in Africa. The infestation by cassava green mites and cassava mealy bugs can cause yield losses up to 80%. Whitefly (*B. tabaci*) adults feed on the underside of young cassava leaves and transmit the cassava mosaic virus and the cassava brown streak virus that are ravaging the cassava crops, with an estimated yield loss of 40% or more in SSA.

The two species of cassava mealybugs, *Phenacocus manihoti* and *P. herreni*, can cause serious yield losses in cassava in Asia and Africa. *P. manihoti* caused severe yield losses in Africa until the introduction of natural enemies from the Neotropics by IITA and CIAT. *Epidinocarsis lopezi*, a natural enemy of *P. manihoti* collected in Paraguay, was released in 1981 in Nigeria and is now established on approximately 750 000 km^2 over a wide range of African ecological zones, helping to maintain low levels of mealybug attack [37]. The other natural enemy that can effectively control cassava mealy bugs is *Apoanagyrus lopezi* (a parasitoid wasp) identified from South Africa.

The control of the Cassava Green Mite (CGM) (*Mononychellus tanajoa*) in Africa and Asia is one of the most serious challenges to cassava production. Shipments of natural enemies from the Neotropics to Africa have been made regularly since 1984 as a part of a joint IITA CIAT biological control effort. The two biocontrol species, *Typhlodromalus limonicus* and *Neoseiulus idaeus*, have been released in several sites in West Africa [38]. Another natural enemy, *Typhlodromalus aripo* (a predatory mite from South Africa), is also found to be effective against CGM. The success of the biological control campaign against CGM in Africa will depend on continued collaboration between international agricultural research centres and national institutions in African countries.

A wide range of plant parasitic nematodes have been reported associated with cassava worldwide. These include *Pratylenchus brachyurus*, *Rotylenchulus reniformis*, *Helicotylenchus spp.*, *Scutellonema* spp. and *Meloidogyne* spp. Of these, *Meloidogyne incognita* and *Meloidogyne javanica* are the most widely reported and economically important [39]. There is less attention at present on nematode problem in cassava.

16.2. MAJOR DISEASES OF CASSAVA

African cassava mosaic disease (CMD), cassava brown streak disease (CBSD), cassava bacterial blight (CBB), and cassava root rots are the major diseases affecting cassava in Africa (FIG.14). In Asia, root rots, CBB, and phytoplasma or cassava frog skin disease attack the cassava crops (FIG.14).

The CMD caused by the cassava mosaic virus is one of the most serious diseases in Africa. It causes the leaves of the cassava plant to wither, limiting the growth of the root and causing severe yield losses in East, West and Central Africa. The virus is spread by the whitefly and by the transplanting of diseased stem cuttings into new fields. This insect transmitted disease is controlled only through the use of healthy planting material in areas where the reinfection rate is slow. Breeding efforts are ongoing for the development of resistant varieties by crossing *M. esculenta with M. glaziovi,* but insufficient virus resistant material is currently available to farmers.

The CSBD has been identified as a major threat to cassava cultivation worldwide. Even when the CBSD leaf withering symptoms are commonly noted, the root necrosis symptoms are less common. Farmers practice a selection for cassava varieties less prone to CBSD root necrosis leading to dependence on a decreasing number of varieties. Recently, CBSD resistant cassava varieties have been developed and released to farmers in Africa.

The CBB caused by *Xanthomonas campestris* is another disease affecting cassava crops worldwide. Successful control of the CBB can be obtained through inoculation of planting material with strains of *Pseudomonas fluorescens* and *P. putida* [40]. *P. putida* can also be used for the control of *Diplodia manihotis*, a root rot pathogen [41]. Another disease cassava anthracnose (*Colletotrichum gloeosporioides*) is of local importance in Africa.

Cassava phytoplasma or cassava frog skin disease (CFSD) is an important disease affecting cassava roots in South America including Brazil and it was later introduced to Asia. The CFSD causes deep lesions in roots, eventually reducing their diameter; therefore, in many cassava cultivars, symptoms are observed only when the plants are harvested. The CFSD infected roots are thin, cork like, fragile, and opaque, covered by a thickened peel. In many cases, roots may be very thin and the bases of stems thicker than normal [42] caused by a fungus, *Sphaceloma manihoticola*us, and it reduces the cassava root yields drastically, mostly in South America. This fungal infection causes significant internode elongation which results in a spindly stem, as well as changes in leaf shape, along with necrotic spots.

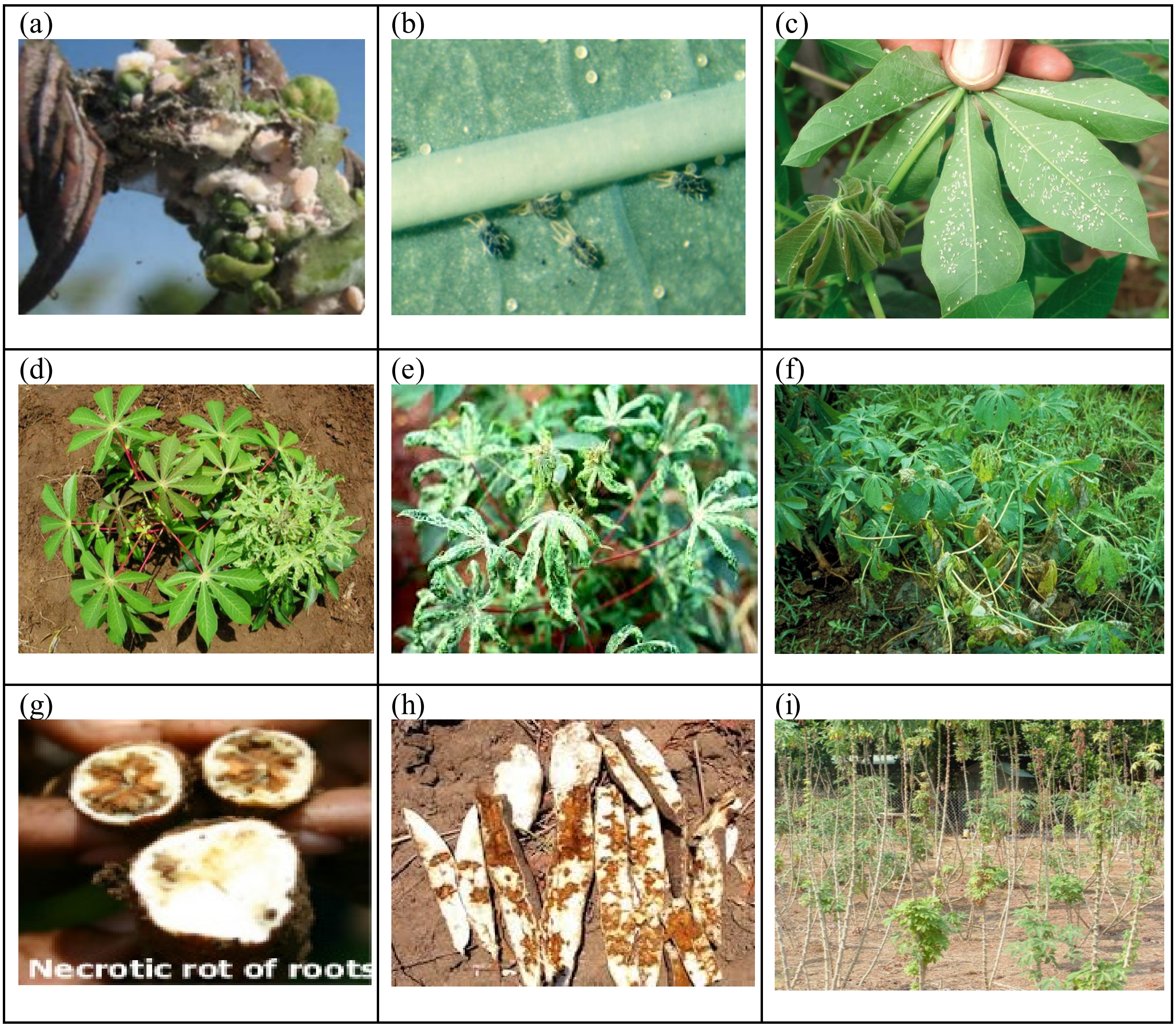

FIG. 14. Major insect, pests and diseases of cassava: (a) cassava mealy bugs, (b) cassava green mites, (c) cassava whitefly, (d) cassava mosaic disease: susceptible vs. resistant types, (e) cassava brown streak disease foliar symptoms (f) cassava bacterial blight (g) cassava mosaic disease: necrotic roots (h) cassava brown streak disease: root necrosis, and (i) cassava phytoplasma or cassava frog skin disease.

16.3. MANAGEMENT OF INSECT PESTS AND DISEASES IN CASSAVA

Insect pests and diseases of cassava are controlled by (a) preventive and curative measures and (b) corrective measures in case of severe outbreaks or in hot spots.

16.4. PREVENTIVE AND CURATIVE MEASURES: INTEGRATED PEST MANAGEMENT

Integrated Pest Management is defined as the integrated use of various non-chemical pest control tactics prior to resorting to the use of chemicals for pest control in hot spots. The three cardinal principles of IPM are: (i) growing a healthy crop by adopting resistant varieties and best crop management practices; (ii) maintaining pest predator balance by establishing and maintaining a healthy agro-ecosystem; and (iii) the strategic use of external pest control inputs that are known to have a minimal impact on the agro-ecosystem. IPM is thus a knowledge intensive approach, one which requires systematic learning through continuous observation and practice (e.g., via Farmer Field Schools) [43]. The sustained hard work required to implement an IPM program will pay off through increased crop yields, reduced cost on purchase and application of pesticides, and improved human and wildlife health, as well as an improved environmental quality. An analysis of 85 IPM projects from 24 countries of Asia and Africa which have been implemented over the past 20 years (1994–2014), indicate that crop yields have been increased by an average of 40.9% while pesticide use decreased by 30.7%, all relative to baseline yields. Unfortunately, policy and institutional support for IPM remains lukewarm [44].

16.4.1. IPM tactics

Farmers currently can use any of the six IPM tactics listed below for managing insect pests and diseases of cassava: (i) genetic: host plant resistance; (ii) agronomic/cultural practices – cultural control; (iii) mechanical methods; (iv) biological control; (v) use of naturally occurring plant products i.e., effective and relatively safe botanicals and microbial bio pesticides; and (vi) judicious chemical control with 'soft' pesticides, which are used on a need only basis.

Genetic Host plant resistance

Host plant resistance to insect pests and diseases is a key component of IPM. Planting cassava varieties that are resistant to insect pests and diseases, and are also tolerant to drought, waterlogging, heat, and cold is a popular and highly cost-effective pest control method, one which is readily available for farmers to adopt. For example, farmers in coastal Tanzania and elsewhere in Africa tend to discard the cassava plants that are severely affected by CBSD and retain those that grow and yield satisfactorily even when infected. By this process, Tanzanian farmers have identified a CBSD tolerant local cassava variety *Nachinyaya* in which the CBSD leaf symptoms are produced, but the development of root necrosis is delayed so much that the full potential yield of healthy roots is obtained [45]. Breeding efforts are ongoing for the development of virus resistant cassava varieties by crossing *M. esculenta with M. glaziovi*. Recently, CMD and CBSD resistant cassava varieties (FIG.15) have been developed and released to farmers in Africa and Asia by the collaborative works of IITA in Africa and CIAT in Asia, both in collaboration with national cassava program. They have also identified cassava varieties that are resistant to cassava whiteflies (FIG.15) that transmit the most damaging virus diseases CMD and CBSD.

Agronomic/cultural pest control methods

Planting of disease free cassava stem cuttings is the first step in the prevention of the spread of cassava virus diseases. It is therefore important to raise the awareness among cassava farmers about the importance of establishing the next crop with healthy planting materials.

Mechanical methods

Removing and/or destroying disease affected cassava plants (or their alternate hosts) is vital in order to prevent the spread of bacterial, fungal and viral diseases of cassava. Cassava farmers seldom practice this method to control the spread of cassava diseases.

Biological control of cassava insect pests and diseases

To control cassava mealy bugs, natural enemies have been introduced into Africa and Asia from the Neotropics as a part of a joint IITA CIAT biological control effort. *Epidinocarsis lopezi*, a natural enemy of *P. manihoti* collected in Paraguay, was released in 1981 in Nigeria and is now established on approximately 750 000 km^2 over a wide range of African ecological zones, helping to maintain low levels of mealybug attack [37]. The other natural enemy that can effectively control cassava mealy bugs is *Apoanagyrus lopezi* (a parasitoid wasp) identified from South Africa.

The two biocontrol species, *Typhlodromalus limonicus* and *Neoseiulus idaeus*, have been released in several sites in West Africa to control cassava green mites (CGM) [38]. Another natural enemy, *Typhlodromalus aripo* (a predatory mite from South Africa), is also found to be effective against CGM.

Successful control of the CBB can be obtained through inoculation of planting material with strains of *Pseudomonas fluorescens* and *P. putida* [40]. *P. putida* can also be used for the control of *Diplodia manihotis*, a root rot pathogen [40, 41].

The success of the biological control campaign against CGM and virus and bacterial diseases will depend on continued collaboration between international agricultural research centres and national institutions in African and Asian countries.

Phytosanitary measures

Being a vegetative propagated crop, cassava hardwood stem cuttings are exchanged between farmers of different regions and even different countries. This traffic in planting material within and between countries is responsible for the inadvertent transmission of pathogens in Africa and Asia. Strict enforcement of phytosanitary measures at national borders is crucial to stem the spread of cassava virus diseases form one region to another.

Surveillance and diagnostics play a vital role in identifying and eradicating destructive diseases of cassava. IITA has launched a virtual network program called the ‘Cassava Disease Surveillance (CDS)’ in Nigeria to facilitate the rapid diagnosis of cassava diseases, communication, and coordinated deployment of emergency response to control such diseases. This interactive program accessible through any internet enabled devices offers effective and economical solutions to the challenges in coordinating and communicating disease outbreaks in the fields and interception of pathogens in the commodities exchanged between country borders. A particular focus of the CDS program is to monitor for CBSD, which is ravaging cassava production in East Africa, but not yet present Nigeria.

The CDS platform enables rapid preliminary diagnosis of cassava disease by visual inspection of suspect specimens. Symptomatic specimens are submitted as digital images by internet enabled devices. These images are immediately analysed by a team of national and international experts. It also includes a coordination framework for regulatory action by the national agricultural quarantine services (NAQS) to contain any threat identified in the field.

Healthy cassava seed systems

Until recently, farmers had very limited access to 'virus free' cassava planting materials. In recent years, with the funding support from the Bill Gates Foundation, the Quality Management Protocol (QMP) has been developed to multiply disease free cassava planting materials and distribute them to farmers. The key components of the QMP are as follows: Primary (centralized) multiplication sites multiplying the virus tested cassava plantlets derived from tissue culture and managed by researchers or qualified seed producers, secondary, and tertiary multiplication sites (usually in farmers' fields) are all assessed, at least once in a year, for quality parameters, primarily in terms of disease and pest incidence and quality of planting materials. The QMP standards for CMD and CBSD incidences ascertained by diagnostic tests are <10% for primary and secondary sites and <20% for tertiary sites in endemic areas. In addition, the management of cassava diseases could be greatly enhanced by raising awareness among growers about the importance of establishing the next crop with healthy planting material.

With this program, healthy, disease free planting materials have been provided to more than half a million beneficiaries in six countries (Kenya, Uganda, Tanzania, Burundi, Rwanda and eastern parts of DR Congo). This QPM protocol provides an important model for other current and future cassava development programs. For successful replication of the QMP based cassava seed systems, basic capacity needs must be strengthened in most countries. Key elements of this include the laboratory and human capacity for virus indexing, as well as the knowledge of QMP and the capacity of the national plant quarantine organization to monitor cassava seed systems.

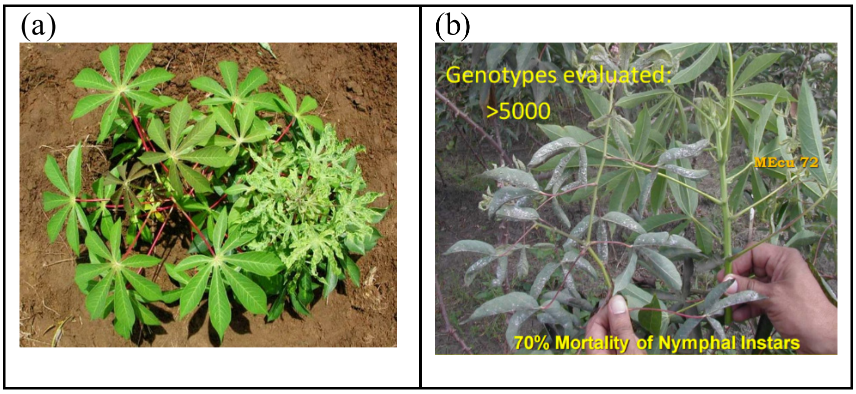

FIG. 15. Use of hostplant resistance for the control of cassava insect pests and diseases. (a) *Cassava mosaic disease (CMD) Susceptible vs. resistant types and (b) MEcu 72 cassava line resistant to whiteflies [46]*

Judicious use of soft pesticides

In the IPM approach, recommended soft pesticides are applied only as a last resort, when all non-chemical pest control tactics fail to protect the crop and the projected risks of crop damage and economic loss are serious. For example, for cassava green mite control, biological measures are recommended when the observed egg laying adults are less than 50 and nymph pupae are less than 200 per plant. Chemical pesticide application is taken up when the population of adult mites reaches a level of 51 to 200 and the nymph pupae are 201 to 500 per plant [46].

Informed decisions about where and how to grow cassava should take into account site specific information such as soil fertility requirements, the risk of soil degradation, climatic conditions, on farm food and animal feed needs, as well as market access and demand. Then the myths will be truly debunked and cassava can be recognized as a hardy, flexible crop with promising economic potential for the poor of the region.

17. HARVESTING AND POSTHARVEST PROCESSING

Cassava being a perennial, it can be stored in the ground for 2–3 months and harvested as and when required. Its wide harvesting window allows it to act as a famine reserve food crop and is invaluable in managing labour schedules [3]. In general, cassava roots are harvested between 6 and 18 months after planting (MAP) [22]. Some early maturing varieties can be harvested at 6 MAP mainly for direct human consumption, but most commercial/industrial varieties are harvested between 8 and 12 MAP. Yields of fresh and dry roots as well as starch increased steadily from 8 to 18 MAP; root and starch yields nearly tripled between 8 and 18 months. Starch contents increased and stabilized 10 MAP (Table 3). Harvesting cassava after 18 months provides an income only every 1½ years, but at a considerable saving in terms of production costs. Harvesting early, at 6–8 MAP, allows for double cropping of cassava with a follow on short duration crop of rice, sweet corn, mung beans, beans, cowpea or groundnut. Rotation of cassava with a grain legume adds biologically fixed N to soils and improves soil organic matter content and related soil properties.

TABLE 3. TIME OF HARVESTING OF CASSAVA ON ROOT YIELD, STARCH CONTENT AND YIELD OF CASSAVA VARIETY RAYONG 1 PLANTED AT THE RAYONG FIELD CROPS RESEARCH CENTER, THAILAND, 1975–79

Age at harvest (months)	Fresh roots yield (t ha^{-1})	Dry root yields (t ha^{-1})	Starch yields (t ha^{-1})	Starch content (%)
8	16.19	6.44	2.31	14.3
10	23.06	8.31	4.81	20.9
12	31.31	10.69	5.94	19.0
14	37.56	13.06	7.38	19.6
16	41.50	15.00	8.69	20.9
18	45.25	16.44	9.19	20.3

Mean values: Source: [52].

FIG 16. Postharvest processing and value addition opportunities. (a) harvesting cassava tubers, (b) transporting cassava roots, (c) cassava peeling (Ghana), (d) cassava grater machine (Philippines), (e) open air sun drying of cassava chips (Nigeria), (f) sun drying of cassava bread (Venezuela), (g) cassava processed into gari (Nigeria), (h) cassava processed into fermented cattle feed, (i) cassava processed into flour (Thailand).

Cassava is usually harvested by removing the tops at 20–30 cm above the ground level and using the remaining stump to pull up the roots manually (FIG.16). If the soil is too hard, the roots can be lifted out of the ground with a pointed metal bar or a metal fork attached to a wooden stick used as a lever. Roots can also be dug out with a pick axe, a hoe or a shovel. Farmers in some parts of Thailand now use a tractor mounted cassava harvesting tool that loosens the soil and lifts up the roots for easy gathering by hand. In Malaysia, a more sophisticated cassava harvesting machine digs the roots and deposits them in an attached wagon. After pulling up the root clumps, the individual roots are cut off from the stump and packed in baskets or sacks for transport to the house, drying floor or starch factory (FIG.16).

Fresh cassava roots are highly perishable after harvest, and therefore, they should be processed within 2–3 days after the harvest. Peeling of cassava roots is a very labour-intensive process (FIG.16). Therefore, breeders are trying to select a cassava variety with a white peel covering the roots. One cultivar, Branca de Santa Catarina, has been selected for this reason.

Drying of the tubers is one simple method of cassava preservation (FIG.16). It is important to note that some methods of drying are more effective than others in terms of retaining β-carotene levels in dried roots. Oven drying at 60°C was shown to maintain 72% of the β-carotene levels though the retention fell to 40% after four weeks in storage. Sun drying only resulted in a 38% retention of β-carotene levels and after four weeks in storage, the levels fell to about 18% [2]. The retention of β-carotene can be improved by pre-treatments such as blanching and osmotic dehydration.

Dried cassava is processed into dried chips for local use and for export as cattle feed, and *gari*, bread, fried chips, and other food products for human consumption in rural processing centres. Cassava flour, cassava starch, cassava/tapioca pearls, and cassava bioethanol are produced in small and large factories located in towns and cities (FIG.16).

Dried cassava roots or chips can be stored for 3 to 6 months. However, during storage, a wide range of insect pests feed directly on the dried chips, causing a 15–20% loss in weight in 3 months.

A large quantity of waste is produced during processing of the cassava roots, mainly consisting of tuber peels (FIG.17). Cassava peels are processed generationally for additional household income in Vietnam in Asia and many countries of SSA. The challenge is to dry the cassava peels from about 60% moisture content to a 12–15% moisture content within 6–7 hours to preserve the quality of the cassava wastes. Sun drying inside a plastic dome will help dry the cassava peels to a safe moisture content of 12–15% within 6–7 hours to get high quality products with very low or no aflatoxins. In addition, a retrofit heat exchanger, that uses palm kernel shells or cashew nut shells as a fuel, has been developed for flash drying of cassava peels. Dried cassava waste can be used as a substrate up to 75% of the growth medium for the production of oyster mushrooms.

FIG. 17. Large amounts of wastes produced during cassava peeling.

18. MECHANIZATION OF CASSAVA PRODUCTION AND PROCESSING

Appropriate mechanization of cassava production and processing (FIG.18) will be helpful to increase labour efficiency, reduce drudgery, and obtain high quality products. Land preparation is the most mechanized in cassava production in many countries, while other operations are less mechanized. Primary processing of cassava like the grating and preparation of dried chips, wet starch preparation, and making *gari,* bread, fried chips, etc. at village level will enhance rural cassava processing enterprises and potentially generate jobs for rural youth and women. Secondary, industrial level processing of cassava into cassava flour, cassava starch, and cassava biofuel ethanol is centralized in towns and cities in Asia and Africa.

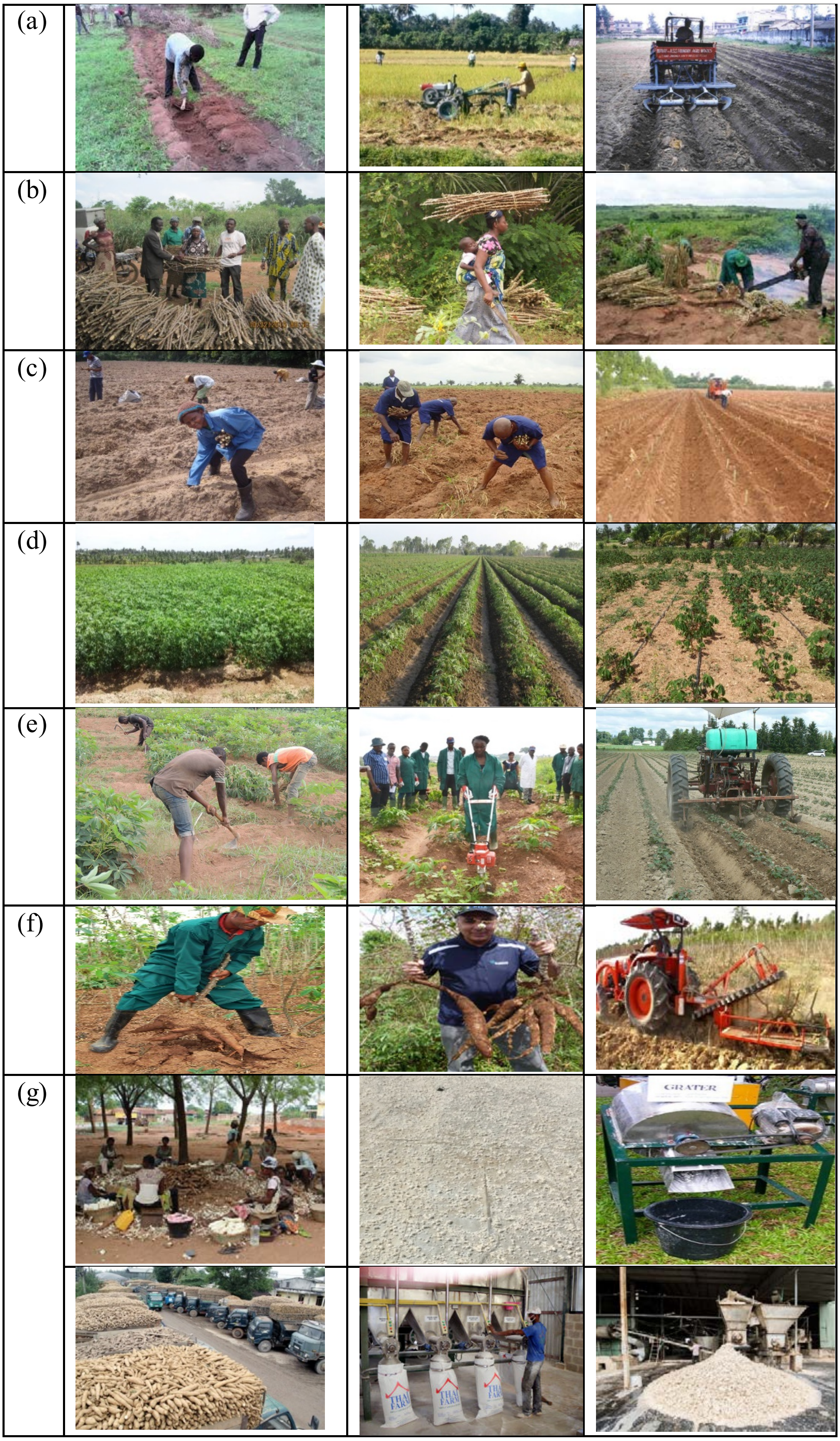

FIG. 18. Progressive mechanization of cassava production and processing operations (a) land preparation, (b) preparation & distribution of stem cuttings, (c) planting of stem cuttings, (d) irrigation, (e) weeding and inter row cultivation (f) harvesting of cassava (g) processing of cassava

19. ECOLOGICAL INTENSIFICATION OF CASSAVA PRODUCTION SYSTEMS

The biggest 21st century challenge for farmers, agricultural scientists, and planners and policy makers is the need for further intensification of agriculture to meet the growing food/feed/fuel/raw materials demand, while at the same time protecting the resource base, ecosystem services and the environment. Farmers have experienced soil degradation with excessive tillage. Excessive tillage often accelerates decomposition of soil organic matter, reduces soil microbial populations and their activity, destroys soil mulch or vegetation cover, increases evaporation of soil moisture, depletes soil fertility and degrades soil structure [47]. Added to this is the further decline of soil fertility due to continuous cropping of cassava and other crops without adding adequate nutrients either through fertilisers or through incorporation of organic materials. Soil erosion is a serious problem when cassava is cultivated on sloping lands. In semiarid areas with uncertain rainfall, cassava crops do suffer from drought stresses which will reduce the cassava yields drastically.

To combat the major abiotic stresses to cassava production, scientists have proposed the conservation agriculture (CA) based ecological intensification of agriculture. By improving soil health, reducing soil erosion, reducing pest and pathogen pressure, increasing the availability of water and nutrients, and increasing soil carbon storage, CA enhances crops' resilience to higher temperatures, drought and flooding; enhances ecosystem services; reduces GHG emissions; and helps to mitigate climate change. It also lowers the production costs through savings on machinery, labour, fossil fuel, irrigation, mineral fertilisers and pesticides.

The technical principles (reduced or zero tillage, soil cover, crop diversification) CA have to be translated into the ecological processes in the field (FIG.19) to reap the many benefits of CA. However, CA is not a 'one size fits all' approach – the methods used to realize its key practices vary according to crops and local conditions [48]. Let us now look at these CA components as applied by farmers in their fields in Asia and Africa and the rest of the world.

19.1. CA THROUGH REDUCED OR ZERO TILLAGE AND ORGANIC MATTER MANAGEMENT

Reduced or zero tillage is considered the most successful resource conserving technology on the plains [49, 50] as well as on sloping lands [17]. When farmers practice reduced or zero tillage, residues from previous crops or leaf litter from nearby vegetation is left on soil surface (FIG.19). Surface mulching with crop residues will help infiltrate rainwater into the soil, conserve soil organic matter and soil moisture, and improve water use efficiency by crops [17]. However, weeds could be a problem in zero till fields, and thus weed control is critical to get high yields.

19.2. SOIL EROSION CONTROL IN CASSAVA FIELDS: MANAGEMENT OF ORGANIC RESIDUES

Both wider spacing adopted for cassava planting and slow early growth of cassava plants, soil is exposed to the direct impacts of rainfall and soil erosion becomes serious problem, especially on sloping lands. However, farmers can reduce the risks of soil erosion by adopting appropriate agronomic and soil conservation measures such as minimum tillage, forming the ridges along the contour, making tied ridges, close plant spacing, mulching, adequate application of nutrients, intercropping with quick growing legumes, growing a cover crop before planting cassava, and forming contour live hedges with grass strips, leguminous trees and shrubs.

Plant resides from previous crops is the principal source of mulch for CA systems. Diversified cropping systems and vegetated borders provide different types of crop residues for use as mulch on soils, especially under zero till cassava systems. In agroforestry systems, certain deep rooted, leguminous shrubs and trees can extract water and nutrients from deep soil layers if water and nutrients are available in subsoil; they also enrich the soil through biological N fixation [49]. On station and on farm trials have shown planting hedge rows of vetiver, *Paspalum atratum*, lemon grass, Tephrosia candida and pineapple were the most effective in reducing soil erosion, while closer plant spacing, fertiliser application, and lemon grass or vetiver hedgerows were the most effective in increasing cassava yields [50].

19.3. CROP DIVERSIFICATION AS A COMPONENT OF CA

Cassava farming can be diversified by planting grain legumes, green manure legumes, cover crops, and leguminous shrubs and trees in the form of crop rotations, intercropping, relay cropping and agroforestry systems. Commonly planted legumes include beans, pigeon pea, cowpea, groundnut and soybean, which are grown mainly for food, and non-edible legumes, such as velvet beans and jack beans, which are used as feed for livestock or as ground cover in planted fallows. Cassava legumes systems diversify production, enrich the soil through biological nitrogen fixation, enhance water use efficiency, and disrupt the life cycle of weeds, insect pests and disease agents. Crop diversification can also improve family nutrition with a variety of foods, and provide higher income opportunities to farmers [51, 49].

FIG. 19. Some examples of ecological intensification of cassava based production systems. (a) zero till field with residues on soil surface, (b) cassava planted on zero till field with maize residues on soil surface (c) cassava on ridges covered by crop residues (d) crop rotation: Early maize crop followed by cassava (Cambodia) (e) cassava beans intercropping (f) cassava maize jack bean intercropping, (g) cassava maize intercropping, (h) Mixed cropping of cassava, papaya, mahogany, cashew nut (West Timor, Indonesia, Photo by Yulius Suni), (i) Contour planting of crops including cassava on sloping land (North Vietnam), (j) crop animal systems: cassava Flemingia macrophilla (forage crop) intercropping, (k) crop animal systems: Goats foraging fallow vegetation and (l) Crop animal system: Carrying cassava clippings for feeding animals.

19.3.1. Cassava legumes rotations

In crop rotations, cassava is planted after a legume or a cereal monocrop is harvested. Researchers in Cambodia are demonstrating that an early planting of maize followed by cassava is highly productive per unit area of land. Researchers in Thailand have shown that when green manures are planted and incorporated into the soil before planting cassava, they increase cassava yields significantly, but farmers are not willing to grow a crop for green manure purpose only. Alternatively, cassava can be planted late in the rainy season after incorporating the fully grown green manure and harvested at 18 months after planting to get very high root yields (38.8 to 46.2 t ha^{-1}) [52], but this rotation system provides only one cassava harvest every two years. Farmers could follow this 2-year system of green manure cassava rotation in alternate years on half of their fields to obtain a more consistent cassava yields and steady income every year.

19.3.2. Cassava legumes intercropping

Intercropping is growing two or more crops together, planted at the same time in the same field. Small scale farmers in most of Africa and in some countries of Asia practice intercropping as a hedge against vagaries of weather and to obtain higher total yields of all crops put together. In intercropping, cassava and legumes are planted simultaneously in the same or in alternating rows. In relay cropping, cassava and legumes are planted on different dates and grow together for at least a part of their life cycle. Green manure crops can be grown as an intercrop between cassava rows and pulled out and used as a mulch on soil surface 2–3 months after planting. In the green manure cassava intercropping system, sword bean was found to be the most effective and it increased the cassava yields from 17.6 t ha^{-1} to 26.9 t ha^{-1}[52].

Among the grain legumes used for intercropping with cassava, groundnut is very popular in Vietnam as it can be grown on similar acid infertile soils as cassava, it doesn't have severe insect pest and disease problems, and it covers the soil well and protects it from water erosion. Intercropping of cassava with mung bean or soybean can be successful sometimes, but at other times, severe drought or pest incidence could wipe out the legume intercrops.

19.3.3. Integrating trees in cassava farms

In agroforestry systems, leguminous shrubs and or trees are incorporated into cassava fields in various designs. Leguminous species used for agroforestry systems include shrubs like glyricidia, leucaena, callinadra, and sesbania and acacia trees like *Faidherbia albida*, and other trees like mahogany. Certain deep rooted, leguminous shrubs and trees can extract water and nutrients from deep soil layers if water and nutrients are available in subsoil; they also enrich the soil through biological N fixation [49]. On station and on farm trials have shown planting hedge rows of vetiver, *Paspalum atratum*, lemon grass, Tephrosia candida and pineapple were the most effective in reducing soil erosion, while closer plant spacing, fertiliser application, and lemon grass or vetiver hedgerows were the most effective in increasing cassava yields [50]. The trees also provide fuel wood (15–20 t ha^{-1}) from the 3rd year of fallow planted with *Sesbania sesban*. Agroforestry improves soil structure and water filtration, which makes rain fed crops including cassava more resilient to drought and the effects of climate change. Conservation agriculture with trees sequesters from 2 to 4 t ha^{-1} $year^{-1}$ of carbon is compared to 0.2 to 0.4 t ha^{-1} $year^{-1}$ under CA without trees [49]. It is, however, important to note that many soil conservation practices do require additional money and labour to install and manage the system, they may reduce the yields of food crops in short term due to competition or by partial occupation of the land meant for growing food crops. Thus, most of the soil conservation practices have advantages and disadvantages, and are often location specific. Therefore, farmers have to choose those practices that are most suitable for their own circumstances, based on their own experience and observations.

19.4. CROP ANIMAL SYSTEMS

Integrating crops and animals in the same farm is another form of diversification when properly integrated and well managed crops and livestock can be highly complementary to each other. Some of the key features of the crops livestock systems are:

- Cassava hay and processed cassava roots or by products as well as forage legumes and grasses are fed to animals and the vegetation from fallow lands will be available for grazing by animals. Animal manure can be added to crop fields to improve soil fertility.
- Livestock, small animals and poultry can play an important role, both as a source of cash income and as food, especially for the poor. Introduction and evaluation of new domestic animal species, such as rabbit or turkey, could broaden the farmers' choice of livestock which are best adapted to their conditions.
- Access to better breeds and vaccination to prevent diseases (bird flu in chickens, or blue ear syndrome in pigs) is important to improve livestock production.
- Development of fodder crops and a cut and carry fodder system to feed the animals will help intensify the livestock production systems. This will also prevent crop damage by free range animals in the summer season, when some farmers with the ability to irrigate can plant crops.

20. THE ROLES OF ISOTOPIC TECHNIQUES TO MEASURE NITROGEN USE EFFICIENCY

The Soil and Water Management & Crop Nutrition (SWMCN) Subprogramme of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, has developed a wide range of nuclear and isotopic techniques for use in soil water nutrient management to enhance nutrient and water use efficiencies, and to also increase the capture of atmospheric nitrogen (N_2) and carbon (C) as well, thereby improving soil fertility for sustainable crop production under changing climate.

Nuclear and isotopic techniques are a complement to, not a substitute for, non-nuclear conventional techniques. These techniques, however, do have several competitive advantages over conventional techniques by providing unique, precise and quantitative data on the dynamics of soil nutrient and soil moisture pools and their fluxes in the soil plant water and atmosphere systems. They are especially useful for assessing the value of selected soil water management technologies which can be tailored to specific agro ecosystems for improving soil fertility, crop productivity and water use efficiency. For details on the principles and applications of the various nuclear and isotopic techniques in soil, water and plant nutrient studies in agro ecosystems, the reader is referred to the IAEA Training Manuals [54] and the review [53].

The major constraints under a subsistence farming system with low soil fertility are the availability of essential plant nutrients, especially N, and water to the plant. Among the essential plant nutrients, N is a key nutrient controlling plant growth and productivity. To take up N from the soil, plants compete with a range of N removal processes including immobilization, leaching, clay fixation, and gaseous emissions of N as ammonia, nitric oxide, nitrous oxide, and di-nitrogen or molecular nitrogen (N_2) into the atmosphere. Because of these losses, the N use efficiency (kg of dry matter produced per kg of N applied) is invariably less than 50% [55, 56]. The extent to which N is removed from soils, or made unavailable to plants by the above biogeochemical processes is of agronomic, economic and environmental importance.

Under subsistence farming conditions, lower soil fertility, soil quality and soil health, is likely to further increase the competition between N uptake by the plant and the soil N removal processes, thereby reducing crop productivity. Quantifying N uptake and the sources of N losses enables researchers to develop 'technology packages' which can enhance N uptake and minimise N losses, thus allowing for sustainable crop productivity even under subsistence farming conditions.

To accomplish these objectives, the use of ^{15}N stable isotopic techniques, at both enriched and natural abundance levels, has great potential to quantify N use efficiency and biological N_2 fixation, and to also identify the sources of greenhouse gases to atmosphere and nitrate pollution in surface and ground waters. To conduct a field experiment for quantifying N uptake by cassava crop, consider the following stepwise field protocol.

In order to determine the N fertiliser use efficiency (NUE) of a cassava crop with a high degree of accuracy, a researcher shall set up a field trial on a relatively flat site with uniform fertility and slope so as to minimise background variations of soil nutrient levels, especially N and nutrients losses via surface runoff (FIG. 20).

FIG. 20. Uniform experimental field – Cassava crop.

Considering an experimental trial of N fertiliser applied at four rates: zero or control (T1), low (T2), middle (T3), and high (T4) of kg N per ha, with four individual replicate plots (each plot being 7 m x 7 m) for each of the four rates of N. (see schematic diagram below – FIG. 21).

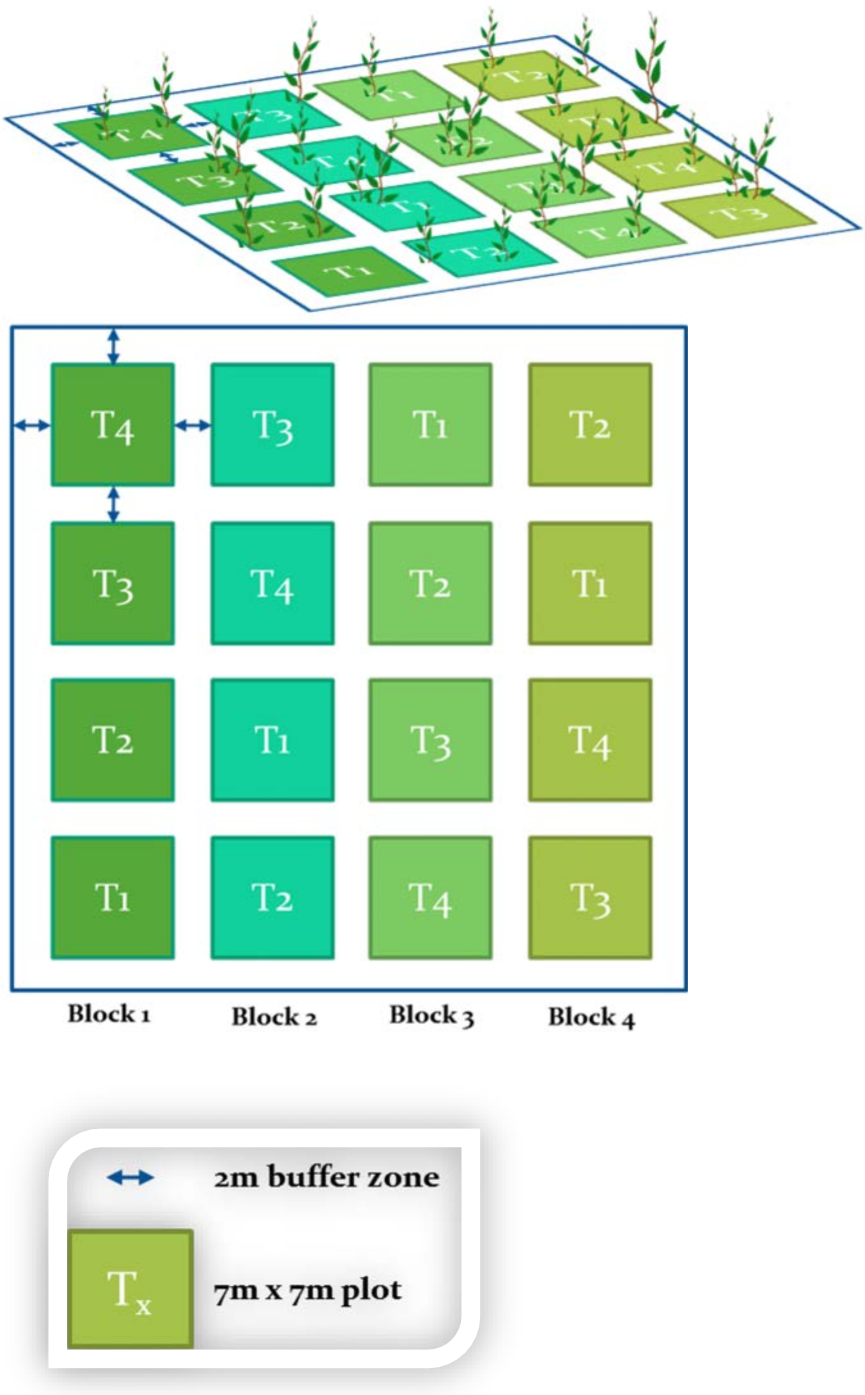

FIG. 21. A schematic diagram of experimental layout.

A `buffer zone' of 2 meters wide on each of the four sides of the experimental site, with a 2-meter-wide strip between each of the individual replicate plots is especially important to prevent contamination of adjacent plots by N via surface runoff after heavy irrigation or rainfall, as well as lateral movement of N within the soil. The individual (replicate) field plots can be a range of sizes, depending on available land area, experimental design, farm resources (machinery) and most importantly available budget. Generally, a larger size for each individual replicate plot (e.g., 7 m long x 7 m wide) is considered as the best for minimizing edge effects (nutrient losses from the fertilised area to an un fertilised area) on final crop yield, with each of four replicate plots being placed within four different treatment blocks.

- Prior to treatment application, four composite soil samples (each composite soil sample consist of ten soil cores from each experimental block) from 0 – 15 cm depth, shall be collected to analyse for key soil properties including soil pH, ECe, total N, total C, exchangeable potassium (K^+) and Olsen P.
- First apply any soil amendments such as lime to correct soil acidity and other chemical fertilisers without N (such as P and K as recommended) and animal manure.
- Assuming 7 m x 7 m (49 m^2) replicated field plot receiving N fertiliser in the form of granular urea (46%N) at rate of 80 kg N ha^{-1} in two split applications during cassava growth period, the amount of urea is calculated below:

Rate of fertiliser application (kg per ha) =

$$\frac{100 \times \text{nutrient element required (kg per ha)}}{\text{\% nutrient element concentration in a fertiliser}}$$

Example:

The amount of urea for the first application (40 kg N ha^{-1}) can be calculated as.

kg of urea required per ha for the first application $= \frac{100 \times 40}{46} = 86.95 \text{ kg urea}$ (1)

As mentioned below, during the N fertilization, one sub plot (4 m^2) of ^{15}N labelled urea within the 49 m^2 replicated plot will not receive ordinary urea. This leaves 45 m^2 area (49 minus 4) which will receive ordinary urea. Thus at 40 kg N ha^{-1} rate, the amount of urea for 45 m^2 is calculated as:

Amount of urea for 45 m^2 = $\frac{86.95 \text{ kg urea}}{10\,000 \text{ m}^2} \times 45 \text{ m}^2 = 0.39 \text{ kg}$ (2)

Where, 10 000 m^2 correspond to the land area of one hectare.

Setting up sub plot for ^{15}N labelled fertiliser:

- For two split applications of ^{15}N-labelled urea, one shall set up two sub plots, each of 2 m x 2 m (4 m^2), separated within the entire 49 m^2 larger replicated plot by a 1 m buffer zone, as shown below (Figure 22). This 4 m^2 sub plot will allow researcher to select a few cassava plants for ^{15}N analysis. The buffer zone will also help to minimize ^{15}N contamination from adjacent sub plot.

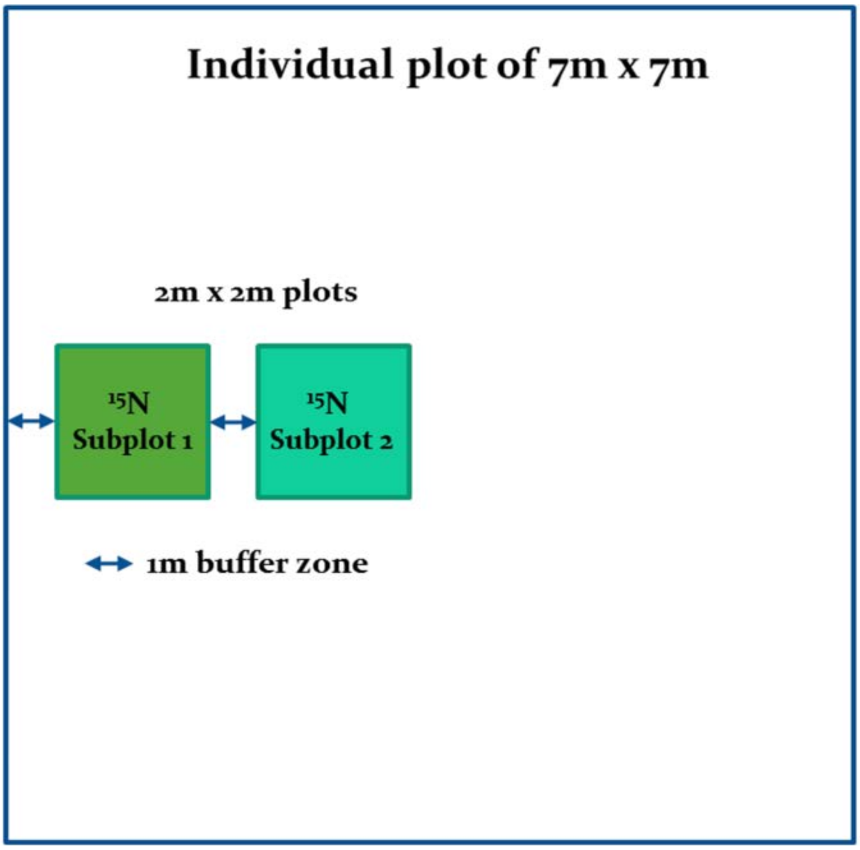

FIG. 22. Schematic diagram of the layout of the two sub plots within a main plot, each with a 1 m buffer zone, each destined for ^{15}N-labeled fertiliser application.

[Mark each sub plot well to avoid any mistake of fertiliser application]

- To ensure that no ^{15}N-labeled fertiliser/residues are present from previous experiments, collect four soil cores (0 –10 cm soil depth) from each of the two sub-plots, then combine them into one sample, and analyse for ^{15}N content. This will establish the initial ^{15}N level in the soil.
- Calculate the amount of ^{15}N-labeled fertiliser (using a maximum of 5 atom % excess) to add to each 4 m^2 sub plot using Equations 1and 2. The amount of ^{15}N-labeled urea at 40 kg N ha^{-1} for a 4 m^2 sub plot comes out to be 34.78 gram.
- Please note that if N fertiliser is applied in a single application, this 5 atom % excess could be reduced to 3 atom % excess (please refer to the dilution procedure at the end of this section).
- Separate the first sub plot for ^{15}N-labeled fertiliser by placing a temporary plastic sheet or any other similar material around the perimeter of the first sub plot. Then, uniformly apply the required amount (0.39 kg) of ordinary urea to the entire (45 m^2) of the larger main plot excluding the first sub plot.
- After application of the ordinary urea, remove the plastic sheet around the first sub plot, carefully weigh out the exact amount of ^{15}N-labeled fertiliser (34.78 gram) using equation 2, and apply ^{15}N-labeled urea evenly by hand to the first sub plot. One shall be aware that ^{15}N-labeled fertiliser such as urea comes as a fine particle therefore extreme care shall be taken while applying to ensure its even application. Fine sand of the same diameter or any other inert material shall be mixed with the ^{15}N-labelled urea to ensure even application. One shall also avoid ^{15}N labelled urea under windy conditions or when a heavy rainfall is expected. If irrigation water is available, it is

important that the experimental plots are supplied with at least 10 to 20 mm of irrigation soon after N fertiliser application to move urea from surface into the soil to minimise the risk of ammonia volatilization.

- When the time arrives for the 2nd split ^{15}N fertiliser application, place a plastic sheet/cover around the perimeter of only the second sub plot of 4 m^2 (this sub plot will have previously received only ordinary urea) to ensure that ordinary urea is applied only to all areas of the main plot except the 2nd sub plot during the 2nd fertiliser application. Then, uniformly apply the required amount (0.39 kg) of ordinary urea to the entire 45 m^2 of the larger main plot, but exclude the 2nd sub plot.
- Remove the plastic sheet, and carefully apply the required amount (34.78 gram) of ^{15}N-labeled fertiliser to the 2nd sub plot as above.
- Carry out normal farm practices like spraying of herbicides and insecticides, and apply normal irrigation volumes until the cassava crop reaches its maturity.
- At the appropriate time, harvest the cassava crop from each sub plot. For ^{15}N uptake by below ground (tubers) and aboveground plant parts (i.e., stems, shoot and leaves), randomly select 2 to 3 cassava plants from each sub plot of ^{15}N; and transfer them to plastic bags. After transporting cassava plant samples to the lab, separate the plant samples into tuber and aboveground plant biomass, wash them with tap water first, then with distilled water followed by taking a sub tissue sample and drying them at 65°C for seven days or until samples are dried to a constant weight.
- After drying, grind the cassava tuber and above ground plant biomass samples separately to a fine powder (for determination of the total N by Kjeldahl or by the combustion method). Then, accomplish the ^{15}N determination by stable isotope mass spectrometry. Be certain to clean the grinder with a brush (and also use a blower), in between grinding the individual plant tissue samples.
- Also collect four soil samples (each 0–15 cm soil depth) from each of the two sub plots; mix them to get one composite soil sample for ^{15}N and total N analysis.

Cassava yield

- To determine cassava yield, select 3 m x 3 m area within each main plot (7 m x 7 m) and harvest cassava crop at the same time as above for ^{15}N analysis. Then, separate the biomass into roots (tuber) and other aboveground plant tissues (i.e., shoot and leaves), and record their fresh bulk weight immediately.
  [Note: Researchers must not use the small ^{15}N plot for biomass production]
- To determine moisture fraction in tubers and aboveground plant tissues, select 2 to 3 randomly chosen cassava plants, from each 3 m x 3 m plot; transfer them to plastic bags, seal each plastic bag using a rubber band to ensure that no water losses occur from the collected plant tissue. After transporting the cassava plant samples to the lab, separate the plant samples into tuber and aboveground plant biomass. Wash the tubers with tap water to remove the soil. Then take sub tissue samples of tuber as well as above ground samples, record their fresh weight, followed by drying the subsamples of tissue at 65°C for seven days.
- Record the dry weights of the plant tissue after seven days in order to calculate their moisture contents. This will provide the researcher with cassava dry matter yield (DM) per hectare as shown in Eq. (3).

$$\text{Cassva tuber or above ground plant tissue DM (kg per ha)} =$$

$$\text{FB Wt (kg)} \times \frac{10{,}000\ \text{m}^2}{\text{harvested area (m}^2\text{)}} \times \frac{\text{SD Wt (kg)}}{\text{SF Wt (kg)}} \qquad (3)$$

Where, FB Wt is fresh bulk weight (kg per m^2) of the harvested area of the sub plot (area (3 m x 3m), and SD Wt and SF Wt are subplot sample's dry and fresh weights, respectively.

CALCULATION OF NITROGEN USE EFFICIENCY (NUE):

The following example provides step by step guidance for estimating fertiliser 'N use efficiency' of a cassava crop.

A field study was carried out with a cassava crop to assess the fertiliser N use efficiency of cassava tuber which received nitrogen fertiliser at the rate of 80 kg N ha^{-1} in 2 split doses (40 kg N ha^{-1} for each of two application times). The experimental sub plot was 4 m^2 in size and the ^{15}N fertiliser was labelled with exactly 5% atom excess. At the end of growth period, assuming the tuber yield from harvested cassava was 8 metric tons per ha and the N content in the tuber, as obtained by Kjeldahl analysis was 1.0 %, the amount of total N removed from the soil by the cassava tuber is calculated below (Eq. 4):

$$\text{Cassava tuber N uptake (kg N per ha)} = \frac{\text{tuber yield (kg per ha) x total N (\%) of tuber}}{100} \quad (4)$$

$$\text{Cassava tuber N uptake} = \frac{8000 \text{ x } 1}{100} = 80 \text{ kg N per ha}$$

The tuber ^{15}N measurements from the 1st and 2nd split applications of ^{15}N-labeled fertilisers showed that an 'atom excess percentage' of 0.75% and 0.80% occurred, for the two sub plots. The fertiliser N use efficiency of the cassava tuber is calculated as follows:

i) Percentage tuber N derived from 1st and 2nd fertiliser application (% Ndff), based on the ratio of tuber 15N [0.75 % and 0.80 %, to fertiliser 15N (5 %)], can be calculated from Eq. 5.

$$\%Ndff = \frac{^{15}N_{tuber}}{^{15}N_{Fertilizer}} \times 100 \quad (5)$$

% *Ndff* for the 1st application $= \frac{0.75}{5} \times 100 = 15\%$

% *Ndff* for the 2nd application $= \frac{0.80}{5} \times 100 = 16\%$

% *Ndff* for the two split applications = 15 + 16 = 31%

ii) From the % Ndff, the amount of N derived from the two split fertiliser applications (Ndff) is calculated as:

$$Ndff = \%\,Ndff \times \text{ N taken up by crop} \quad (6)$$

$$Ndff = \frac{31}{100} \times 80 = 24.8 \text{ kg N per ha}$$

[Note: The above equations (Eqs. 5 and 6) can also be used to calculate *Ndff* of the aboveground cassava plant tissues (shoot and leaves), if such information is needed.]

Finally, fertiliser N use efficiency *(FNUE)* is calculated from *Ndff* (24.8) and N rate applied 80 kg N ha^{-1} to cassava crop.

$$FNUE = \frac{Ndff}{\text{Total fertiliser N applied}} \times 100 \tag{7}$$

$$FNUE = \frac{24.8}{80} \times 100 = 31\ \%$$

Thus, in this study the cassava tuber derived 31% of its N from the applied ^{15}N-labeled urea fertiliser, with the remaining N (69%) coming from the pre-existing soil N pool.

An example for ^{15}N-labeled Urea Dilution:

For diluting 1 kg of ^{15}N-labeled urea with 5 atom % to 3 atom %, please see the calculations below (Eq. 8) using a mixing model based on the following relationship:

$$f_A + f_B = 1 \tag{8}$$

Where, f_A and f_B refer to the fractions of labelled fertiliser and un labelled fertilisers, respectively.
First calculate the fraction of ^{15}N-labeled fertiliser with 5 atom % (f_A) which will be required for mixing with un labelled fertiliser to make 3 atom % using Eq. 9 below:

$$f_A = \frac{3 - 0.366}{5 - 0.366} = 0.56841 \tag{9}$$

Then calculate the fraction of un labelled fertiliser using Eq. (10) below:

$$f_B = 1 - 0.5684 = 0.43159 \tag{10}$$

Thus, for 1 kg of labelled fertiliser with 3 atom %, weigh 0.56841 kg of 5 atom % fertiliser and mix it with 0.43159 kg of un-labelled fertiliser.

21. STEPWISE FIELD PROTOCOL OF BEST MANAGEMENT PRACTICES (BMPS) FOR CASSAVA PRODUCTION IN ASIA AND SUB-SAHARAN AFRICA

Cassava (*Manihot esculenta*) is a hardy crop that can survive even in harsh environments, but root yields are very low (2–3 t ha^{-1}) under these harsh conditions. Declining soil fertility and soil erosion are serious problems in traditional cassava farms in Asia and Africa. The potential fresh root yield of cassava is as high as 80 t ha^{-1}, but farmers can obtain 15 to 40 t ha^{-1} with improved cassava varieties and good soil and crop management practices as given below or region.

Improved cassava varieties: Use locally recommended improved cassava varieties in each country.

Preparing healthy planting materials:

Stem cassava cuttings are used for planting. Choose healthy, disease free, improved high yielding cassava varieties as mother plants. The stems for planting are normally cut when the mother plant is 8–12 months old. For most cassava varieties, the cut stems can be stored vertically in the shade for 1–2 months. Take 15–25 cm long cuttings from the lower and middle parts of the cut stems for planting.

Land configuration for protecting soil and water resources: On flat lands, where most farmers plant cassava, the land is ploughed, harrowed, levelled, and ridges and furrows are formed either manually or with the help of furrow openers attached to a tractor. The ridges are 75 to 100 cm wide at their base. The furrows are made gently sloping along the natural slope of the field to help drain the excess rainwater, if necessary, during heavy rains.

On sloping lands, it is better to establish hedgerows of grass *Paspalum atratum* or *Tephrosia candida* or pineapple across the slopes and plant the cassava crop between hedge rows. This will minimise erosion of top soil rich in organic matter and nutrients, reduce rainwater runoff, and improve rainwater infiltration and water retention in soil – all leading to sustainable high cassava yields year after year.

Spacing and plant population:

Cassava mono crop: The planting density for cassava varies from 10 000 to 25 000 plants per hectare, depending on the fertility level of soil and the branching habit of the varieties chosen for planting. The general spacing is 75 to 100 cm between rows or ridges and 50 to 75 cm between planting holes within rows or ridges for a mono culture crop of cassava. Densely planted cassava covers the bare soil much faster than a crop planted at a lower density. Missing plants, if any, should be replaced within 2–3 weeks from the original date of planting.

Cassava inter cropping: A wider spacing of up to 200 cm between rows or ridges (with 50 cm between plants in a row or a ridge) is used when cassava is intercropped with 1 to 3 rows of fast growing legumes such as groundnut, cowpea, beans, soybeans etc. or with cereals like maize or millet. Intercropping cassava with grain legumes will reduce the risk of complete crop failure due to climate change, reduce soil erosion and improve soil fertility, fix atmospheric N_2, increase cash flow, and improve total crop yields.

Planting method: The stem cuttings can be planted vertically, or in a slanted position by pushing the lower part of the cutting 5–10 cm deep into the soil. Alternatively, stem cuttings can be planted horizontally at 5–7 cm depth.

Rainfall management: In rain fed areas, farm ponds can be dug to harvest rainwater which can be used to wet the crop during periods of severe droughts. Mulching of the soil surface with crop residues or grass clippings will help reduce soil erosion, suppress weed growth, and enhance infiltration of rainwater into the soil and reduce evaporation of soil moisture.

Water saving irrigation methods: Wherever water is available, the cassava crop is irrigated by flood, furrow or drip irrigation, once every 10 to 15 days, depending on local weather. In terms of water use, drip is more efficient than furrow irrigation which in turn is more efficient than flood irrigation.

Balanced fertiliser application: In most soils, cassava responds well to K >N >P, unless the soil is extremely deficient in N. K application is thus critical, not only to increase crop yields, but also to increase starch content in roots. Combined use of both organic and mineral fertilisers is always better than either alone for balanced nutrient application. Field trials indicate that for an average fresh root yield of 15 t ha^{-1}, the crop will take up 30 kg N, 8 kg of P_2O_5, and 24 kg K_2O. Thus, the ratio of nutrient requirement for cassava will be 3 N – 1 P_2O_5 – 3 K_2O. Based on this ratio, we suggest the following NPK rates for cassava crops:

TABLE 4. KEY STABLE ISOTOPES AND THEIR ABUNDANCES IN AGRO-ECOSYSTEMS [53]

Targeted cassava fresh root yield (t ha^{-1})	Nutrients required (kg ha^{-1})		
	N	P_2O_5	K_2O
10	20	7	20
20	40	14	40
30	60	20	60
40	80	26	80

The suggested rates of N, P and K can be modified based on the results of actual field trials in different soil types.

Method of fertiliser application: All the P and half of the N and K can be applied at planting, while the remaining N and K are applied 2–3 months after planting. The fertiliser can be band-applied near the crop rows, or spot-applied 5–10 cm from the base of the plants.

In problems soils, before applying fertilisers, soil amendments such as plant ash or biochar (charcoal) have to be applied to correct specific problems like soil acidity, Al toxicity, salinity, and very low level of soil organic matter.

Integrated weed management: Cassava is a poor competitor with weeds due to its slow early growth. Weed control is thus critical during the early growth period (up to 3 months after planting). Farmers should effectively combine cultural, manual, mechanical and/or chemical weed control methods.

Integrated pest management: The three cardinal principles of IPM are: (i) growing a healthy crop by adopting resistant varieties and using best crop management practices; (ii) maintaining pest predator balance by establishing a healthy agro ecosystem; and (iii) the strategic use of external pest control inputs that are known to have a minimal impact on the agro ecosystem.

Harvesting and postharvest processing: Cassava, being a perennial crop, can be harvested as and when required. In general, cassava roots are harvested between 6 and 18 months after planting (MAP). Some early maturing varieties can be harvested at 6 MAP for direct human consumption, but most commercial/industrial varieties are harvested between 8 and 12 MAP.

Mechanization: Appropriate mechanization is critical to improve labour productivity. Locally produced improved tools for harvesting cassava roots, for slicing roots to make dry chips, and for chopping cassava leaves for producing silage will improve labour productivity, reduce drudgery, and increase overall profitability in cassava farming.

Commercialization of cassava products: Fresh cassava roots are cooked and eaten by people or sold in local markets. Dry cassava root chips or root meal and cassava leaf silage or leaf meal are excellent livestock feeds that have high potential in local or international markets. Cassava starch is another high value product from cassava roots.

22. CONCLUSIONS

Cassava is a highly versatile and a resilient crop for farmers to grow. It is a hardy crop because it can grow in poor soils and in drought prone areas with little risk of a complete crop failure. However, to obtain high and sustainable yields over long term, the crop and soil should be well managed: selection of the locally adapted high yielding cassava varieties; use of the healthy, disease free stem cuttings that are 15–25 cm long; planting at the right time of the year at optimum spacing for mono and intercropped cassava systems; weeding 2–3 times during the first 3–4 months after planting; supply of all plant nutrients at adequate levels through the application farm available organic residues and manures supplemented by required quantity of chemical fertilisers, particularly K and N fertilisers; effective weed control for the first 3–4 months after planting through integrated weed management; integrated management of insect pests and diseases (IPM); harvesting the crop at the right time and improved handling of the harvested roots during collection, transport, processing, and storage. Above all, it is possible to intensify cassava production in a sustainable manner through the use of ecological intensification methods. Nuclear and isotopic techniques can play a crucial role in quantifying soil water and nutrient to develop climate smart agricultural practices to improve soil fertility and enhance cassava production.

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ABBREVIATIONS AND ACRONYMS

FAO	Food and Agriculture Organization of the United Nations, Rome
BASICS	Building a Sustainable, Integrated Seed System for Cassava
C	Carbon
CA	Conservation Agriculture
Ca	Calcium
CBB	Cassava bacterial blight
CBSV	Cassava brown stream virus
CDS	Cassava Disease Surveillance
CFSD	Cassava frog skin disease
CGM	Cassava green mites
CGIAR	Consultative Group for International Agricultural Research
CMD	Cassava mosaic disease
CIAT	International Centre for Tropical Agriculture
CT	Conventional tillage
CTCRI	Central Tuber Crops Research Institute
Cu	Cupper
DM	Dry matter
ECe	Electrical conductivity
FBWt	Fresh bulk weight
Fe	Iron
FNUE	Fertiliser N use efficiency
FYM	Farm yard manure
GHGs	Greenhouse gases
HCN	Hydrogen cyanide
HQCF	High quality cassava flour
IAEA	International Atomic Energy Agency
IITA	International Institute of Tropical Agriculture
ISFM	Integrated Soil Fertility Management
IPM	Integrated pest management
K	Potassium
MAP	Month after planting
m	Million
Mg	Magnesium
Mn	Manganese
N	Nitrogen
NAQS	National Agricultural Quarantin Services
Ndff	N derived from fertiliser
NRCRI	Nigerian Root Crops Research Institute
NT	No tillage
NUE	Nitrogen use efficiency
P	Phosphorus
PPD	Postharvest physiological deterioration
QMP	Quality Management Protocol
RTB	Research Program on Roots, Tubers and Bananas
RF	Ridges and furrows
RT	Reduced tillage
SOC	Soil organic carbon
SOM	Soil organic matter

SSA	Sub-Sahara Africa
SSNM	Site specific nutrient management
SDWt	Subplot dry weight
SFWt	Subplot fresh weight
SWMCN	Soil and Water Management & Crop Nutrition
UNFCC	United Nations Framework Convention on Climate Change
WHO	World Health Organization
Zn	Zinc
ZT	Zero tillage

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18-03481

International Atomic Energy Agency
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ISBN 978–92–0–101718–5
ISSN 1011–4289