A Training Manual on Integrated Management of Watersheds

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Editors
S P Wani, P Pathak, and T J Rego

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An Introduction to Integrated Management of Watersheds

The term "watershed" strictly refers to the divide separating one drainage basin from another. However, over the years, the use of the term watershed to signify a drainage basin or catchment area has come to stay. Hydrologically, watershed could be defined as an area from which the runoff drains through a particular point in the drainage system. Watersheds exist naturally and due to human intervention for agricultural purposes the changed ecology and management practices affect the well equilibrated ecologies. If watersheds are not managed properly then the natural resources are degraded rapidly and in due course cannot be used for betterment of humans. Soil, water, air, and vegetation are the most important natural resources for the survival of human beings and animals.

For maximum production of vegetation all the resources have to be managed efficiently and effectively. Efficient management of these resources is possible through a suitable unit of management so that these resources are managed and handled effectively, collectively, and simultaneously. Watershed management can be defined as rational utilization of all the natural resources for optimum production to fulfill the present need with minimal degradation of natural resources such as land, water, and environment. Water can be managed if a watershed is taken as a unit. Since soil and vegetation can also be conveniently and efficiently managed in this unit, a watershed is considered the ideal unit for managing the vital resources of soil, water, and vegetation. In a watershed, people and animals are the integral parts of the watershed community. Humans and animals depend on the watershed for their survival and in turn are responsible for the good or bad use of the resource. Participation of people is essential for the success of watershed programs. Participatory watershed management is a process which aims to create a self-supporting system which is essential for sustainability. The concept of participatory watershed management emphasizes a multi-disciplinary and multi-institutional approach. The process begins with the management of soil and water which eventually leads to the development of other resources. Human resource development and large-scale participation is essential since finally it is the people who have to manage their resources. People's or farmers' participation is the key to the success of any integrated watershed development program. Moreover, the watersheds should be used as an entry point for convergence of various natural resource management-based activities for improving the livelihoods rather than soil and water conservation programs.

The main aims of the watershed programs in rainfed areas are:

- Enhancing crop production and increasing farmers' incomes; and
- Minimizing degradation of natural resource base.

The overall objective of the watershed program is to empower researchers and extension staff with new techniques and methods of developing and managing watersheds for enhancing and sustaining crop productivity of the semi-arid tropical areas of Asia. The specific objectives are to:

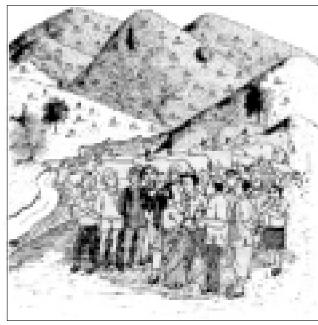
- Introduce practices for sustained increases in agricultural productivity.
- Reduce soil degradation and increase farmers' incomes through better management of natural resources.
- Improve livelihoods of rural people in the watershed.

Integrated Watershed Management

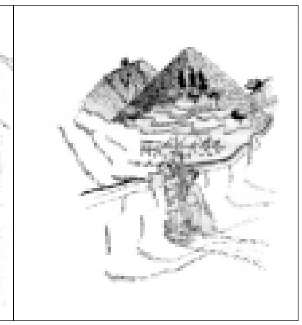
P Pathak, S P Wani, R Sudi, and Ch Srinivasa Rao

What is Watershed?

A watershed is defined as any surface area from which runoff resulting from rainfall is collected and drained through a common point. It is synonymous with a drainage basin or catchment area. A watershed may be only a few hectares as in small ponds or hundreds of square kilometers as in rivers. All watersheds can be divided into smaller sub-watersheds. As each watershed or sub-watershed is an independent hydrological unit, any modification of the land used in the watershed or sub-watershed will reflect on the water as well as sediment yield of the watershed.



Big watershed



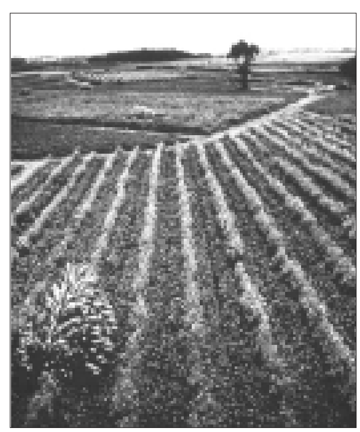
Small watershed

Why Watershed-based Development and Management?

The intensification of land use in the traditional agricultural setting is self-defeating because it is exploitative and results in greatly increased runoff and soil erosion, reduced groundwater recharge, downstream flooding of agricultural lands and cities as well as an accelerated sedimentation of reservoirs that negates irrigation and power investments. Consequently, the land resource base is shrinking and its productive capacity diminishing. The solution to these problems lies in evolving development programs that recognize the natural topography and the drainage patterns of the land. In many areas, it is not unusual to experience significant quantities of runoff at one time of the season and serious drought at another time. The collection of excess water and its utilization to provide greater stability to rainfed agriculture appears to be a viable development alternative in such areas, particularly if soils are shallow. Thus, the watershed, or catchment, is the natural framework for resource development in relation to crop production systems and resource conservation and utilization.

Integrated Watershed Approach

A watershed is made up of the natural resources in a basin, especially water, soil, and vegetative factors. Watershed management is the integration of technologies within the natural boundaries of a drainage area for optimum development of land, water, and plant resources to meet the basic needs of people and animals in a sustainable manner. This includes land improvements, rehabilitation, and other technical works as well as betterment of people.



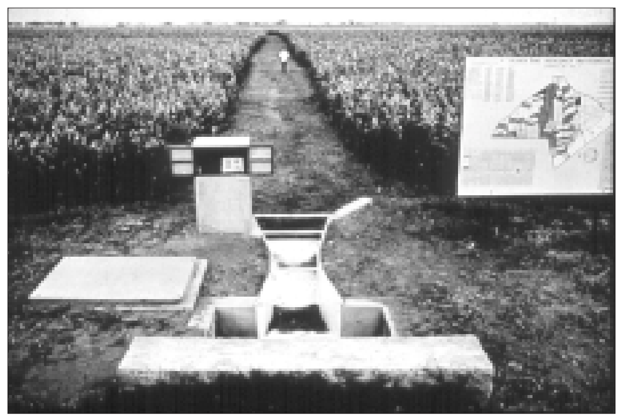
Major Objectives of Integrated Watershed Management

Integrated watershed management aims to improve the livelihood of community/farmers by increasing their earning capacity through offering improved facilities required for optimum production. Some of the major objectives of integrated watershed management are to:

- Conserve soil, rainwater, and vegetation effectively and harvest the surplus water to create water sources in addition to groundwater recharge.
- Promote sustainable farming and stabilize crop yields by adopting suitable soil, water, nutrient management and crop management practices.
- Cover the non-arable area effectively through afforestation, horticulture, and pasture land development based on land capability class.
- Enhance the income of individuals by adopting alternative enterprises.
- Restore ecological balance.

Principles of Integrated Watershed Management

Watershed-based resource utilization involves the optimum use of the area's precipitation for the improvement and stabilization of agriculture on the watershed through better water, soil, and crop management. Sound watershed management means improving overall productivity, controlling floods, and reducing erosion as well as sediment accumulation. Some of the basic principles of integrated watershed management are:



- Utilizing the land according to its capability.
- Adequate vegetative cover during the rainy season.
- Conserving as much rainwater as possible at the place where it falls.
- Draining out excess water with safe velocity and diverting it to storage ponds/recharge ponds for future use.
- Effective utilization of surface and groundwater resources.
- Avoiding gully formation and checking at suitable intervals to control soil erosion and recharge groundwater.
- Optimizing productivity per unit area, per unit time, and per unit of water.
- Adopting integrated soil, water, nutrient, and pest management options.
- Increasing cropping intensity and land equivalent ratio through intercropping and sequential cropping.
- Safe utilization of marginal lands through alternative land use systems.
- Ensuring sustainability of the ecosystem benefiting the man-animal-plant-land-water complex in the watershed.
- Stabilizing total income and cutting down risks during aberrant weather situations.
- Improving infrastructural facilities with regard to storage, transportation, and marketing.

Benefits of Watershed Development

Improved watershed management offers many potential benefits for the farmer, the local community, and the larger cross section of society.

For the farmer:

- Increased production and higher profits.
- Improved water availability for crop production.
- Improved soil quality and better drainage.
- Improved livelihoods .

For the local community:

- Lower land-development costs.
- Reduced flooding and waterlogging.
- Reduced soil erosion and land degradation.
- Increased agricultural productivity.
- Improved livelihood options.
- A more dependable, clean water supply for domestic and industrial use.

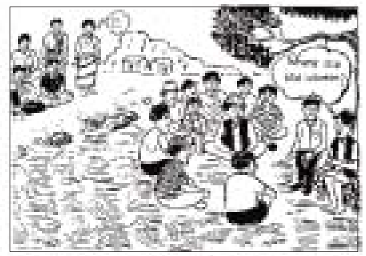
For the larger cross section of society:

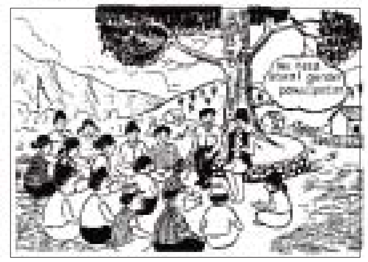
- Less danger from floods to downstream cities and farmlands.
- Reduced sedimentation of costly irrigation projects.
- Better conservation of natural resources.

Community Participation in Watershed Management

P Pathak, S P Wani, R Sudi, and Ch Srinivasa Rao

In the past, watershed management was synonymous with increase in crop productivity. Today, it is synonymous with poverty alleviation and sustainable development of watersheds for the welfare of the population or land users. Watershed management is seen in its entire complexity, where interrelated factors and their interactions are considered with the objective of poverty alleviation and food security of the populations. The past models of development, e.g., government or outside agency driven development programs (often top down) have not proved to be successful and have resulted in a waste of available resources (budgets).





With the new focus on poverty alleviation and food security through appropriate natural resources management, both people and natural resources become the focus of watershed management. Participation of local community in watershed development and management is essential to sustain the watersheds.

Community Interventions

There are many activities which are not effective, when attempted at an individual field or farm level, but call for simultaneous community action. For some areas/activities community interventions are essential. These activities are:

- Management of social forestry and pasture lands.
- Management of surface and groundwater resources.
- Maintenance of major structures.
- Management of gully control structures.
- Maintenance of drainage ways.
- Resolution of conflicts.
- Management of community funds.
- Management of other common property resources.

Key Elements in Participatory Processes

Some critical elements, which need to be integrated into watershed management programs have often been overlooked in the past. The following critical elements are the key elements in participatory processes for integrated watershed management:

- Participatory, multidisciplinary, and multi-sectoral approach.
- Envisioning of both farmers and professionals for integrated watershed management.
- Farmers' empowerment and ownership of watershed management processes and programs.
- Assured and quick benefit generation by watershed management programs.
- Land use titling/tenure for farmer ownership of watershed management programs.
- Mainstreaming gender concerns specially those of women and other disadvantaged groups.

Basic Principles for Effective Community Participation

Mutual respect

All people must be accepted as they are with their strengths and weaknesses.

Active involvement

Active involvement of the people is a pre-requisite for participation. Participation patterns must continue from planning through evaluation.

Agree to disagree

Participation requires an implicit and explicit understanding to agree and disagree and to accept the common interest above personal interest.

Building consensus

Collective responsibility for decisions made.

Commitment to action

Collective commitment to action on the basis of agreed upon decisions and plans.

Community Participation Activities

To improve community participation in watershed management the following activities are important:

- Establishing farmers' organizations.
- Capacity building of farmers in the following areas:
  - In planning and implementation of watershed project.
  - Conflict management.
  - Fund management.

Land Preparation and Field Operations

S P Wani, L S Jangawad, and L Mohan Reddy

One of the most important requirement for crop production in agriculture is to conduct different field operations at the proper time during the crop growth period and after crop harvest. The field operations must be cost effective, labor saving, and efficient.

Pre-sowing and After Harvest of Postrainy Season Crop

Plowing of land soon after the harvest of postrainy season crop is beneficial as given below:

- Easy for farm operations with available moisture (less draft requirement).
- Summer reconditioning of soil occurs thereby killing pests and pathogens.
- Harrowing and cultivation with summer rains will be easy.
- Proper seedbed preparation or broadbed-and-furrow (BBF) layout for sowing is on time.
- Less weed infestation in the following rainy season crop.

The above operations are done with the help of bullock-drawn tropicultor, with multipurpose tool bar attachment for all field operations. Even local implements with bullocks and tractor mounted implements can be used for the operations.

Improved Land Management System

Land preparations for layout of BBF system on grade requires plowing after the harvest of postrainy season crop. With summer rains, harrowing and cultivation help to make a good BBF system layout for growing the next rainy season intercrop or sequential crop. Using the existing natural drains by shaping into a parabola and putting grass all along the drain, a grassed waterway is formed. Broadbed-and-furrow are made on grade from ridgeline to waterway by fixing a key line of 0.6% (0.4–0.8%) grade. A tractor or tropicultor attached with two ridgers 150 cm apart and with chain or wooden plank for proper bed shaping is used. The operations are continued until there is a change in keyline and the beds and furrows are formed one after another using furrow as the baseline of the recently formed BBF. The total width of BBF system is 150 cm. The bed width is 100 cm; this is the crop zone for growing different crops. The furrow is 50 cm wide and 15 cm deep which serves as a traffic zone as well as for draining excess runoff water during the rainy season.

Advantages of BBF System

- Better moisture conservation, good surface water management, and better disposal of excess water.
- Reduction of soil erosion and nutrient loss.
- All field operations are faster and labor saving.
- Better crop establishment, higher yields and profits.
- Convenient for supplemental irrigation during postrainy season crop.
- Less soil compaction in the cropped area (bed) and improved soil physical characteristics.

Sowing and Fertilizer Application

Tropicultor mounted seed-cum-fertilizer drill is used for sowing different crops and combinations with required row and plant spacing on BBF and flat on graded contour. Sowing under dry soil conditions, one week before rainy season helps in easy operation in black soils (except for oilseed crops). The seed required for different crops as per the recommended practices is used. The fertilizer required for the initial crop establishment is applied conveniently at the time of sowing as per the recommendation. Top dressing is generally with a nitrogen fertilizer (urea) and applied 30 days after sowing. The advantages of seed-cum-fertilizer drill are:

- Proper establishment of crop in exact row and plant spacing arrangements.
- Less weed problems, and suitable for interculture operations.
- Seed and fertilizer placement is uniform in required quantities and at proper depth of application.
- Easy operation, more area covered in less time, saves labor.
- Sowing of various intercrops and sequential crops is possible.

Interculture Operations

Interculture operation is faster and the time required is reduced because of the furrows. The cultivator mounted on tropicultor with required number of rows and spacing is used along with ridgers (without wings) for furrow shaping. The operations are done generally at 21 and 45 days after sowing the crop. The interculture operation in soybean, maize, or sorghum crop is done until the crop height reaches about 75 cm. The area covered is large and per unit time requirement of labor for weeding is reduced. Interculture operation helps in loosening the soil for rainwater infiltration between the rows. Weeding is done by laborers when required.

Harvesting Rainy Season Crop and Planting Postrainy Season Crop

Soybean, maize, and sorghum under sequential and intercropping systems are harvested during October 2nd week. Planting of postrainy season crop (chickpea or safflower) is done immediately in between the harvested rows without any land preparation. Sowing is done with the help of bullock drawn seed-cum-fertilizer drill.

Cropping Systems

Sequential cropping system

The crops are harvested leaving the stubble in the field to preserve the moisture which promotes the establishment and growing of postrainy season crops. There is no additional land preparation required for sowing. Chickpea (4 rows with 30 cm row spacing), safflower (3 rows with 50 cm row spacing), or any other suitable crop can be planted between the rows with stubble. When early withdrawal of rain takes place, moisture availability is not enough to establish the crop in shallow soils. The furrows are used for supplemental irrigation. Deeper soils hold more moisture for postrainy season crops. Therefore, irrigation is not required for crop establishment. After harvest of chickpea crop the land needs to be plowed and left for summer reconditioning and preparation of a good seedbed for next cropping season. The major cropping patterns are:

- Maize (2 rows at 75 cm spacing) + chickpea (4 rows at 30 cm spacing).
- Sorghum (3 rows at 50 cm spacing) + chickpea (4 rows at 30 cm spacing).
- Soybean (4 rows at 30 cm spacing) + chickpea (4 rows at 30 cm spacing).

Intercropping system

Rainy season crops such as maize, sorghum, and soybean can be planted along with pigeonpea. These crops are harvested in October. In the intercropping system, long-duration pigeonpea remains until February of the following year. After harvest of pigeonpea the land is plowed and left for summer reconditioning and preparation of a good seedbed for next cropping season. The cropping patterns used are:

- Maize/pigeonpea (2 rows at 50 cm + 1 row at 150 cm spacing).
- Sorghum/pigeonpea (2 rows at 50 cm + 1 row at 150 cm spacing).
- Soybean/pigeonpea (4 rows at 22.5 cm + 1 row at 150 cm spacing).

Land and Water Management

P Pathak, R Sudi, and Ch Srinivasa Rao

In the semi-arid tropics, heavy rains may occur at any time. Heavy rains during the dry season or the early rainy season when crop cover is limited may result in serious runoff and erosion. Also, even a smooth land surface without any local depressions may not provide adequate surface drainage conditions, particularly on black soils during the extended periods of rainfall that frequently occur. Thus, there is a need for an improved land and water management and drainage technology that can protect the soil from erosion throughout the season and provide for water control.

Objectives

The main objective of land and water management is to sustain productivity through efficient utilization of natural resources such as land and rainfall while minimizing land and environmental degradation. The specific objectives are to:

- Increase rainwater use efficiency for crop production.
- Reduce runoff and soil loss.
- Increase water availability through improved surface and groundwater development and management.

Water as the Integrator

There is one common element in nearly every scheme of watershed development – an increased demand for water. Higher economic development invariably brings about higher water use. Consequently, the proper management of water resources is an essential component of development. From another viewpoint, water is the best index of "watershed management", i.e., if a watershed is properly managed for water, then it is also likely to be properly managed in other ways.

Farm-based Land and Water Management Activities

- Broadbed-and-furrow landform.
- Contour/graded bunding and vegetative bunds.
- Gated-outlet contour bunding.
- Ridge and furrow cultivation.
- Graded furrows.

- Graded border strips.
- Scoops (or pitting).
- Tillage.
- Flat on grade cultivation.
- Contour cultivation.
- Combination of earthen bunds + vegetative barriers.
- Mixed crop rows.
- Mulching.
- Vegetative barriers – plant *Gliricidia* on field bunds to stabilize bunds, conserve rainwater and soil, and produce nitrogen-rich organic matter.
- Field drains.

Community-based Activities

- Grassed waterways.
- Surface runoff storage tanks.
- Check tanks and check-dams.
- Percolation/groundwater recharge tanks.
- Gully control structures (double-row post-brush dams, double-row post-stone dams, single-row post-stone dams, stone-wall dams, cushion dams, masonry dams, gabion structures).

Some Requirements of Land and Water Management Systems

In planning an improved land and water management system, the characteristics of soil and climate as well as farm size and human, capital, and power resources are considered. Some specifications of an improved land and water management system for rainfed cropping areas are:

- Avoid water collection in large bodies and large streams, except in a protected grassed waterway.
- Lead the water slowly off the land in small streams uniformly spaced over the land (watershed) so as to reduce erosion, increase water-intake opportunity time, and provide drainage during prolonged rainy periods, especially on deep black soils (Vertisols).
- Provide year-round protection against erosion, even during occasional storms of the hot dry season.
- Establish grasses in the drainage ways which are highly productive and palatable so as to provide nutritious forage for milch or draft animals and to protect against erosion of the drainage ways.
- Use a combination of forage legumes and grasses to minimize nitrogen requirements and provide more nutritious forage.
- Provide a storage facility (tank) to collect and store surface runoff from high-intensity storms as back-stopping for rainfed agriculture.
- Recharge groundwater to improve the groundwater availability for agriculture and other uses.

Benefits of Improved Land and Water Management Systems

Improved land and water management systems offer many potential benefits, as given below, for the farmers and for the large cross section of society.

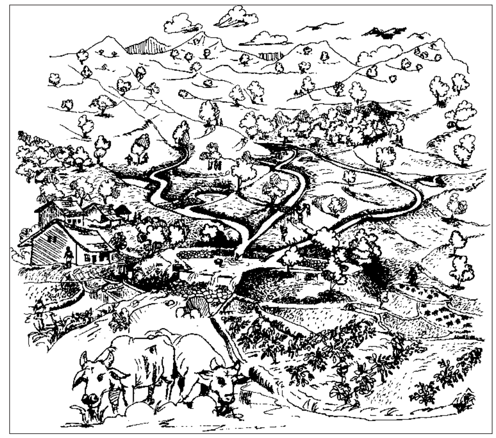
- Improve soil moisture and surface drainage.
- Reduce soil erosion and land degradation.

- Reduce runoff amount and peak rates of runoff.
- Improve soil tilth in the cropping zone.
- Increase crop yields and profits.
- Reduce the power and time requirements of agricultural operations.
- More efficient use of rainfall with excess water stored for supplemental irrigation.
- Conveniently maintained with minimum tillage.
- Lower land-development costs.
- Better conservation and utilization of natural resources.

Water Management in Watersheds

Piara Singh and P Pathak

Proper management of soil and water is essential to meet the basic needs of human beings for food, fiber, and fuel, and for fodder for livestock. Rainfall is the main source of water for crop production in rainfed agriculture. It must be efficiently managed and used for stabilizing crop production as well as for maintaining ecological balance in watersheds. Low rainfall areas have frequent dry spells causing severe damage to agricultural operations and crop production. Even in high rainfall areas, dry spells within the rainy season may cause fluctuations in crop production. Flooding due to heavy downpour may result in water loss with concomitant losses of soil and nutrients. Therefore, it is practical to develop integrated water conservation and management practices to mitigate drought and to moderate floods. Rainwater can be managed both at field scale (farmers' level) and at watershed scale (community level) to derive maximum benefit. Water management in watersheds includes:



A watershed

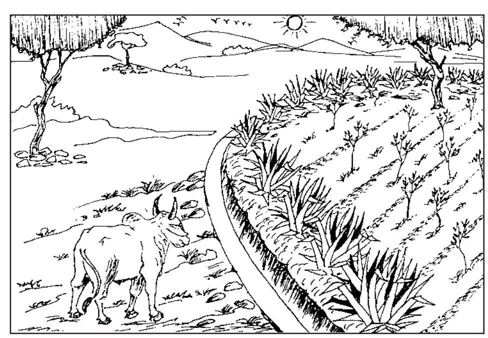
- Collection of water in crop lands to increase infiltration.
- Collection and harvesting of excess rainfall.
- Efficient storage of harvested water.
- Water application (lifting and conveyance).
- Optimal utilization of applied water for maximum benefit.

Water Management at Field Scale

There are several practices which could be applied at field level for proper management of water. The prominent ones are discussed.

Bunding

Contour bunds, graded bunds, and field bunds are made to control the flow of water as well as to conserve more water in the soil. The bunds are made as per the soil, rainfall, and landscape characteristics.



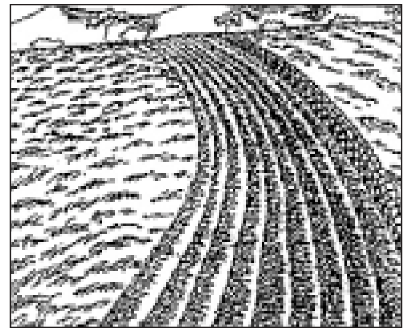
Bunding

Land configurations

Land configurations such as broadbed-and-furrow and ridges-and-furrow are made on grade to conserve and dispose off the rainwater from the fields.

Agronomic measures

Contour cultivation is a common practice wherein all field operations including tillage, weeding, sowing, etc. are carried out along the contours in the field.



Contour cultivation

Water Management at Watershed Scale

Water management at watershed scale generally requires involvement of communities for creating an additional resource of water, managing it, and harnessing the benefits of this resource for various purposes. The activities in this category range from management of waterways between fields to storing of excess water above or below ground. Some of these practices are discussed.

Waterways

Waterways are made between fields to safely dispose off excess rainwater out of the field without much soil erosion.

Farm ponds

Grassed waterways lead to farm ponds where excess rainwater is collected for supplemental irrigation during the dry periods or for animal use.

Check-dams and gully plugging

Check-dams and gully plugging control soil erosion as well as facilitate percolation of rainwater into the ground.

Gully plugging

Percolation tanks

Percolation tanks such as check-dams and gully plugging help in recharging the groundwater.

Conjunctive Use of Groundwater and Rainfall

For increasing crop productivity and sustainability of agriculture in a region, conjunctive use of rainfall and groundwater in a watershed is essential. Over exploitation of groundwater will adversely affect long-term sustainability of agriculture in the region. Crops that give more benefit per unit of irrigation should be grown. Cropping systems should be restricted to growing seasonal crops with low water requirements. Crops which require perennial irrigation and large amounts of water such as rice and sugarcane should not be cultivated.

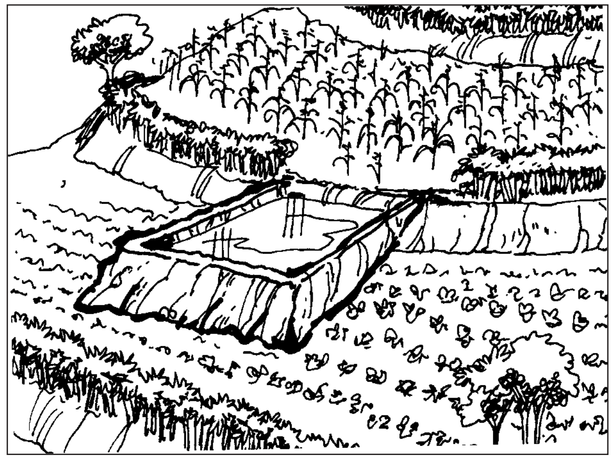
Efficient Methods of Supplemental Irrigation

Irrigation methods that minimize unproductive losses of water during lifting, conveyance, and water application to crops should be encouraged; e.g., scheduling of irrigation to crops at sensitive growth stages to derive maximum benefits of applied water, and alternative furrow irrigation or drip irrigation to minimize losses to increase overall water use efficiency.

Benefits

The benefits of proper water management in a watershed are:

- Increased crop productivity and profits.
- Reduced soil erosion and better land quality.
- Improved surface drainage and reduced waterlogging.
- Increased groundwater recharge.
- Increased water availability for drinking for humans and animals.
- Long-term sustainability of agriculture.
- Improved agro-ecology of watersheds.



A farm pond

Sustainable Cropping Systems for Optimum Resource Use and Income Generation

A Ramakrishna, T J Rego, V Nageswara Rao, and M S Kumar

Poor yields and uncertainty of production are the main problems in rainfed cropping. The major cause is erratic rainfall during the monsoon season. Also, inadequate rainwater management techniques and conventional agronomic practices further reduce the chances of improving production in such areas. The traditional cropping systems that are followed in drylands are not necessarily efficient in terms of utilizing resources in a given location. Research has indicated that there still exists a lot of potential to enhance the productivity in rainfed areas which can be exploited by adopting suitable agronomic and resource management practices.

The Problem with Traditional Cropping Systems

The existing cropping systems in rainfed areas are mostly considered as subsistence systems wherein the farmer tries to produce everything he/she needs. The evolution of cropping system was determined mainly by the physical characteristics of land, climate, availability of labor, capital, and need of the household for food and fodder. Until recently, crop production was based on the utilization of the inherent fertility of the soil without use of inputs such as fertilizers and pesticides.

Varieties grown in drylands are long-duration types which invariably suffer from moisture stress after cessation of monsoon rains. Their response to inputs and high level of management is very low. Hence these traditional cropping systems are characterized by low and unstable yields.

Cropping systems differ according to climate and soil types. In regions of low rainfall (400 mm), short growing season (2 to 2½ months), and shallow soil, a single cropping system involving a long fallow period (October–June) is the rule rather than exception. Mixed cropping as means of insurance and risk distribution is very common. With increasing rainfall and growing season, cereal crops such as pearl millet, sorghum, maize, or upland rice are grown. In areas having 400–750 mm annual rainfall, monocropping with traditional long-duration crops is common. Even in areas having an annual rainfall of >750 mm and a soil storage capacity of 150–200 mm available moisture, farmers grow either a rainy season crop or a postrainy season crop on residual soil moisture after fallowing during the rainy season. Thus, the cropping period is underutilized. The traditional practices followed further lead to poor yield per unit area in drylands.

What are the Opportunities?

Effective growing season concept based on soil types and rainfall should be the basis for identifying sustainable cropping systems in different agroclimatic zones. In rainy season, the rainfall both in terms of quantum and distribution decides the effective growing seasons.

Crops and varieties

Selecting suitable crops and varieties will not only help increase production of a single crop but also help increase cropping intensity. Many criteria have been set out for selecting a crop variety to meet the requirement of drylands; however, the capacity to produce fairly good yield under limited soil moisture conditions is the most desired trait. Cultivars identified for rainfed areas should be short-duration, drought tolerant, and high-yielding types. By replacing the traditional varieties with improved cultivars, yield can be increased up to 30% in drylands if other inputs are not limiting.

Crops should also be selected based on the soil depth. Pearl millet performs better than sorghum on light and shallow soils. Roots of crops like castor or pigeonpea penetrate compact subsoil better than sorghum or millet. Greater yield advantage would accrue from rainy season cropping in the heavier soils. This may call for provision of field drainage in black soils receiving high rainfall.

Crop substitution also helps in improving yields in drylands. Therefore, more efficient crops for a given situation should be introduced to replace traditional crops.

The farmers of dryland areas attach greater importance to food crops. Rarely would they buy food from the market. This aspect should be considered in introducing a new crop. Grain legumes and oilseeds can be selected to replace less remunerative cereals. Decisions should be taken on the basis of marketability and the value of the new crops. Legumes and oilseeds improve the economic status of farmers and also provide required nutrition. For any crop substitution, an efficient transport system should be available to move the produce from areas of production to areas of consumption.

Cropping strategy

In regions receiving 350–600 mm rainfall and having 20 weeks of effective growing season only single cropping is possible in redsoils, shallow black soils, deep Aridisols and Entisols. In deep black soils, a single postrainy season is possible. Intercropping is possible in regions having 20–30 weeks of effective growing season in areas receiving 650–750 mm of rainfall. Double cropping is assured in areas receiving >750 mm of rainfall and having an effective growing season of >30 weeks. With the availability of improved dryland technologies like rainwater management, choice of crops and agronomic practices, a greater proportion of drylands can be brought under intensive cropping system (Table 1).

Table 1. Potential cropping systems in relation to rainfall and soil type.

Rainfall (mm)	Soil type	Effective growing season (weeks)	Suggested cropping systems
350–600	Redsoils and shallow black soils	20	Single rainy season cropping
350–600	Deep Aridisols and sandy soils	20	Single cropping either in rainy or postrainy season
350–600	Deep black soils	20	Single postrainy season cropping
600–750	Red soils, black soils, Entisols	20–30	Intercropping
750–900	Entisols, deep black soils, deep red soils, Inceptiosols	30	Double cropping with monitoring
>900	Entisols, deep black soils, deep red soils, Inceptiosols	>30	Double cropping assured

Intercropping

Planning of cropping system should be done yearly on entire catchment basis. The type of planning should lead to a proper balance between food, fiber, and fodder crops. When the rainfall is 500–700 mm with a distinct period of moisture surplus, intercropping system should be adopted for improved crop production (Table 2). Even in higher rainfall areas (750–1100 mm) intercropping facilitates growing either cereal-legume or legume-legume system of different maturity patterns. Intercropping minimizes risk of crop failure in drylands. Mixed cropping (mixing seeds of two or more crops and broadcasting the mixture) should be avoided as it hinders post-sowing operations. Choice of varieties within the crops is very important to harness total intercropping advantage. Cereal-legume intercropping systems should be advocated to:

- Minimize fertilizer use.
- Reduce pest and disease incidence.
- Produce balance foods.
- Provide protein rich legume fodder for cattle.
- Take full advantage of growing season.

Table 2. Efficient intercropping systems for rainfed lands.

Intercropping system	Row ratio	Plant population	
		First crop	Second crop
Sorghum/pigeopea	2:1	180,000	60,000
Maize/pigeonpea	2:1	70,000	60,000
Soybean/pigeonpea	4:1	250,000	60,000
Pigeonpea/black gram or mung bean	1:2	60,000	120,000
Groundnut/castor	5:1	250,000	60,000

Sequential cropping

To maximize economic returns from the cropping system, emphasis should be placed on growing season, integrated soil, water and nutrient management, and integrated pest and disease management. Special emphasis should be laid on oilseeds and pulse crops (Table 3). In addition, timely land preparation and sowing, suitable method of sowing, contingency planning for aberrant weather, balanced fertilization, runoff water collection and life saving irrigations, and need based pest and disease management are prerequisites for successful and productive cropping systems.

Table 3. Efficient double cropping systems for rainfed lands.

Cropping system (kharif-rabi)	Kharif crop		Rabi crop	
	Plant population	Row spacing	Plant population	Row spacing
Soybean-chickpea	250,000	30	330,000	30
Maize-safflower	70,000	90	166,000	30
Maize-chickpea	70,000	90	330,000	30
Mung bean-sorghum	250,000	30	120,000	45
Mung bean-sunflower	250,000	30	90,000	45
Black gram-sorghum	250,000	30	120,000	45

1. Kharif = rainy season; rabi = postrainy season.

Low monetary input systems

For realizing full yield potential of any crop, optimum plant population per unit area is very important. Plant population depends on the seed rate as well as on the time and method of sowing. Early sowing provides 40–100% yield advantage over late sowing. First soaking rains enable the crops to make use of early season rains and major portion of their life cycle is completed before the cessation of rains. This also facilitates timely sowing of postrainy season crops. To accomplish this, timely field preparation preferably before the onset of monsoon is a prerequisite. Therefore, summer tillage is useful.

Cropping systems for aberrant weather

Rainfed agriculture is gambling with weather. There is a need for making adjustments for aberrant weather situations like (i) delayed onset of monsoon; (ii) long gaps in rainfall; and (iii) early cessation of rains. The recommended strategies for such situations are choice of alternate crops, ratooning and thinning, use of urea spray for rapid regeneration, emergency nurseries for upland rice, and provision of life saving irrigation for moisture stressed crops. When the onset of rains is delayed, it is better to replace cereals with suitable legumes or oilseed crops.

Cropping systems and fertilizer use

While designing a cropping system, care should be taken to see that it economizes the fertilizer use. In a cereal-cereal rotation, besides higher consumption of fertilizers, native soil fertility also gets depleted. Hence systems should be developed in such a way that phosphates are applied to legumes, and nitrogen to cereals, and these crops may be grown alternatively. Split application of fertilizers in relation to crop needs and moisture availability also helps in increasing fertilizer use efficiency.

Conclusion

The traditional cropping systems in drylands are characterized by high risk and low yield. Low risk will continue to be the guiding principle in developing cropping systems in view of the socioeconomic conditions of the dryland farmers. The problem would be how to combine low risk and high yield. The following approaches may help:

- Select efficient, productive, and economically viable cropping systems.
- Adopt non-monetary inputs like selection of appropriate variety, timely sowing, appropriate planting method, and maintenance of adequate plant stand.
- Use balanced quantities of fertilizers.
- Follow integrated pest, disease, and weed management.
- Use life saving/supplemental irrigation.
- Use legumes and oilseeds for crop diversification.

Integrated Nutrient Management in Dryland Agriculture

T J Rego, S P Wani , G Pardhasaradhi, and L S Jangawad

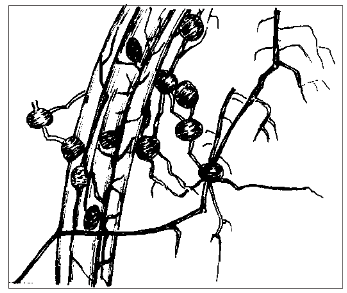
All plants require 16 nutrient elements for their normal growth and development. Of these nitrogen (N), phosphorus (P), and potassium (K) are required in large quantities even though all nutrients are equally important. A fertile soil supplies most of the plant nutrients adequately as per the crop requirement. Due to continuous cropping and multiple cropping in fertile lands as well as cultivation in poorer marginal lands, crop nutrient requirement is not met completely by the soil. The nutrients required in moderate to small quantities are supplied by the soil in most areas except in highly eroded soils. However, plant nutrients that are required in large quantities have to be supplied through external sources to the soil. External sources of plant nutrients are: organic manures; biological nitrogen fixation; and mineral or inorganic (commercial) fertilizers.

Organic Manures

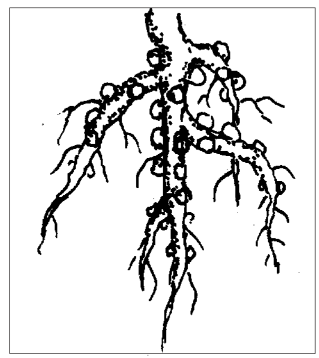
- Farmyard manure (FYM) – 100 kg supplies:
  0.5 to 1.0 kg N
  0.1 to 0.3 kg P
  0.5 to 1.0 kg K
  Other nutrients in smaller quantities
- Compost (rural and urban) – content varies with the composition
- Concentrates
  - Oil cakes
  - Poultry manures
  - Bone meal
  - Fish meal
  - Slaughterhouse waste
- Crop residues – 100 kg sorghum stalks contain:
  0.2 to 0.5 kg N
  0.02 to 0.04 kg P
  0.7 to 1.3 kg K
- Green manures
  - In situ: *Sesbania*, *Crotalaria*
  - Ex-situ (on bunds and wastelands): *Gliricidia*, *Pongamia*
  - Most of the legume green manures contain 2% N.

In addition to N, P, K, organic manures supply other plant nutrients unlike fertilizers. Compost can be prepared in the village itself using weeds, crop residues, etc. New methods by using earthworms can hasten the preparation. Crop residues as such can be used provided they do not have other uses and there is enough time for decomposition. Green manure legumes such as *Gliricidia*, *Sesbania*, and other leguminous shrubs and small trees can be grown on bunds and wastelands. They provide nearly 50 kg N ha^{-1} in addition to small quantities of other nutrients. All these bulky organic manures not only supply plant nutrients but also increase soil organic matter resulting in improved soil physical conditions; nutrient losses are reduced and nutrient availability is improved through the support of microorganisms. In many farm conditions, availability of FYM has been declining due to decrease in animal populations for various reasons. Therefore, compost making and green manure production should be encouraged. Concentrates like oil cakes are costly and many of them have alternate uses. Poultry manure and town compost should be used in greater amounts. But, transporting these manures is costly.

Biological Nitrogen Fixation (BNF)



Most legumes fix atmospheric N in their root nodules and often they are almost self-sufficient up to 80% of their requirements. Crop residues of these legumes can be used or they can be exclusively grown as green manure crops. The N-fixation of legumes can be improved by treating the seeds with *Rhizobium* culture. Even crop rotation with grain legumes (mung bean, black gram, and chickpea) or intercropping of pigeonpea with cereals (sorghum or maize) benefit the succeeding crops by about 20 to 40 kg N ha^{-1} resulting in 0.5 to 1 ton of extra grain yield of cereals. Some important aspects of BNF are:



- BNF is an integral part of N cycling in nature.
- *Rhizobium* inoculation is practiced instead of fertilizer N application to ensure adequate N nutrition of legumes.
- Efficient strains of *Rhizobium/Bradyrizobium* supplied as inoculants of seed or soil are used as biofertilizers.

Use of Biofertilizer through Seed Inoculation

- Different crops require different rhizobia.
- Select the right type of biofertilizer (inoculant).
- The inoculant must be fresh and within the expiry date limit.
- Use well-tested inoculants produced by reputable manufacturers.
- Users in India must insist on inoculants with ISI mark.
- Specify rate of inoculant per kg of seed.
- Specify the fungicide/insecticide/*Rhizobium* treatment sequence.
- Prepare inoculum slurry using a sticking agent such as jaggery, rice porridge, gum arabic, etc.
- Mix seeds with inoculum slurry by hand.
- Dry seeds on a plastic sheet kept under shade.
- Sow seeds within 48 hours after inoculation.
- Cost of biofertilizers varies from Rs 20–80 ha^{-1}.

Mineral Fertilizers

Mineral fertilizers are concentrated simple fertilizers such as urea, single super phosphate, and muriate of potash or complex fertilizers like di-ammonium phosphate (18:46), and 17:17:17, etc.

Approach

An integrated approach has to be followed. First, use all farm available sources of nutrients like FYM, compost, green manure, etc. Later, the remaining nutrient amounts of recommended dose for particular target yield of specified crop should be supplemented by inorganic fertilizers. Improved methods of application of manure and fertilizers along with proper timing will enhance the efficiency of nutrients.

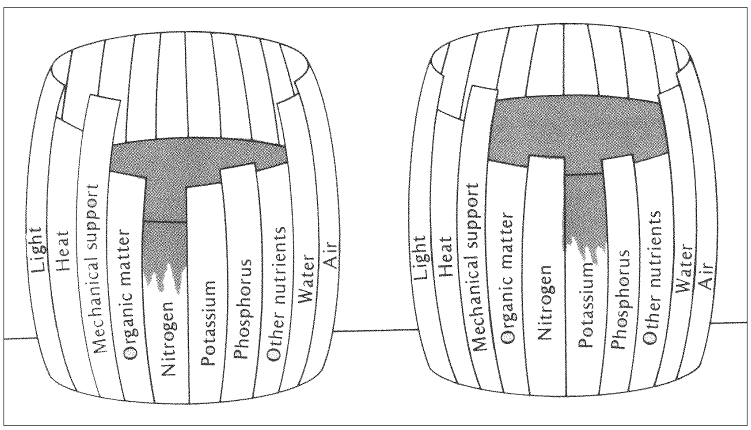
Benefits

Integrated nutrient management is economical because it reduces the dependency on costly fertilizers. This approach also supplies most of the plant nutrients, improves soil structure, and reduces losses of nutrients from soil. It will also make the soil more productive for years to come.

Balanced Nutrient Application

T J Rego and G Pardhasaradhi

A sorghum crop yielding 1 t of grain on an average removes 20 kg nitrogen (N), 3.5 kg phosphorus (P), and 30 kg potassium (K) ha^{-1} and small quantities of calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn), manganese (Mn), boron (B), molybdenum (Mo), iron (Fe), copper (Cu), and chlorine (Cl). When the land is fertile, crops can be grown year after year without adding any external nutrients and good yields up to 5 t ha^{-1} can be obtained. It is like a good bank balance, wherein money can be withdrawn continuously for use as and when required. But after some years the nutrient supply, specially of those nutrients which are needed in greater amounts like N, P, and K, drastically declines and yields decrease. Infertile soils have poor reserves of plant nutrients and cannot support cropping for a longer period unless external supply is made. Even though some nutrients are required by plants in large quantities and some in very small quantities, all nutrients are equally important and deficiency of any one of them will drastically affect plant growth and yield. Fortunately most soils have good reserves of micronutrients except those soils which are eroded and where topsoil was lost. Fortunately, most black soils have good reserves of K and red soils have moderate supply of K; hence, initial need for K input in red and black soils is not required. The phosphate fertilizer is not subjected to losses but its availability in soil is only 15–20% of the applied P in the first year and is slowly available to the succeeding crops. Nitrogen is subjected to loss and under best management practices only 50% is utilized by the crop.



Balanced Nutrient Approach (Assumptions and Calculations)

- Farmer wants 3 t of sorghum grain ha^{-1}.
- Sorghum crop in 1 ha should absorb: $20 \times 3 = 60$ kg N; $3.5 \times 3 = 10.5$ kg P; $30 \times 3 = 90$ kg K; Small quantities of other nutrients
- Without adding any nutrient, 1 t or less grain yield is obtained from 1 ha which means soil supplies: 20 kg N; 3.5 kg P; Adequate amounts of K and other nutrients
- Nutrient supply from external sources to soil: 60–20 = 40 kg N; 10.5–3.5 = 7.5 kg P

- Farmer has 40 cartloads (2000 kg) of good quality farmyard manure (FYM) which supplies:

$$\frac{1 \times 2000}{100} = 20 \text{ kg N}$$

$$\frac{0.2 \times 2000}{100} = 4 \text{ kg P}$$

- Nutrient quantity from other sources:

40–20 = 20 kg N
7.5–4 = 3.5 kg P

- N fertilizer (urea) efficiency is 50%.
  Thus urea required is:

$$\frac{20 \times 100}{50} = 40 \text{ kg N} \cong 85 \text{ kg}$$

- P fertilizer [single super phosphate (SSP)] efficiency is 20%. Thus SSP required is:

$$\frac{3.5 \times 100}{20} = 17.5 \text{ kg P} \cong 200 \text{ kg}$$

Implications

For increased crop yields, a balanced supply of plant nutrients is essential. Soil nutrient availability is tested for efficient use of fertilizers. Even micronutrients may also become deficient with intensive cropping in future. At present, nutrients like K may not be needed in red soil for most cereals, but if crop production is continued without K, after some years K may also be needed. For crops like potato and vegetables even the K supply of red soils may not be sufficient and this has to be supplemented. Already nutrients like S, B, and Zn are deficient in some soils. Therefore, balanced nutrient supply of all deficient elements is a right approach to harvest optimum yields.

Vermicomposting

S P Wani, K P Nagavallemma, and M Babu Rao

Earthworms are one of the major soil macro-invertebrates. They improve soil fertility and soil health. They eat farm residues and vegetable peelings and convert them into a nitrogen (N)-rich compost called vermicompost. By using vermicompost, water-holding capacity of soil can be increased; crops grow healthy and produce more and food and fodder quality is improved. Vermicompost contains 1.0 to 1.5% N, 0.8% phosphorus (P), 0.7% potassium (K), and also many other micronutrients [calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), zinc (Zn)]. With all these benefits importance of vermicompost is increased. It is easy to produce at low cost.

Selection of Earthworms

Earthworms are mainly divided into two types: burrowing type; and non-burrowing type. The non-burrowing type of earthworms (*Eisenia* spp, *Eudrilus* spp), available in local markets, is used for preparing vermicompost. These earthworms are red or purple, live on the soil surface, and eat 90% organic waste materials. The burrowing type of earthworms (*Pertima* spp) is generally seen in rice fields. These earthworms are pale in color, live inside the soil, and eat 90% soil; these are not selected for vermicomposting.

Types of Organic Materials

Vermicompost can be prepared from all types of organic residues such as:

- Agricultural residues
  - dry organic wastes (sorghum straw, rice straw after feeding cattle, dry leaves, pigeonpea residues, groundnut husk, wheat husk)
  - waste vegetables
  - soybean residues
  - weeds (particularly *Parthenium hysterophorus* before flowering)
  - sugarcane trash
- Sericultural residues
- Animal manures
- Dairy and poultry wastes
- Food industry wastes
- Municipal solid wastes
- Biogas-sludge
- Bagasse from sugarcane factories

Vermicompost Preparation

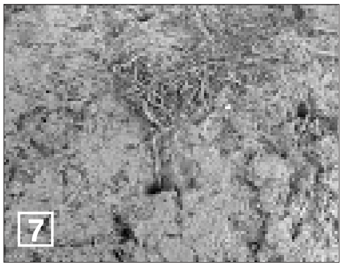
Vermicompost can be prepared by different methods in shady areas:

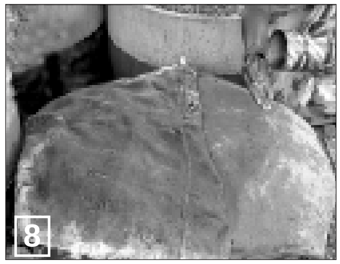
1. On the floor in a heap;
2. In pits (up to 1 m depth);
3. In an enclosure with a wall (1 m height) constructed with soil and rocks or brick material or cement; and
4. In cement rings.

The procedure for preparation of vermicompost is similar for all the methods. The preparation in cement rings is described below (see Figs. 1–12).

Step-wise procedure

- Cover the bottom portion of a cement ring with a polythene sheet (1).
- Spread a layer (15–20 cm thick) of organic waste material on the sheet (2).
- Sprinkle rock phosphate on this layer (3).
- Prepare cowdung slurry (4).
- Sprinkle the slurry as a layer.
- Fill the ring completely with the material in layers (5).
- Paste the top portion of the ring with cowdung or soil (6).
- Allow the material to decompose for 20 days.





- After 20 days release selected earthworms through the cracks (7).
- Cover the ring with wire mesh or gunny bags to prevent birds from picking the earthworms (8).
- Sprinkle water at 3-day intervals to maintain adequate moisture and body temperature of the earthworms.
- Check compost after about 2 months. Vermicompost is ready in 2–2½ months. It is black and light, and has no smell (9).

- When the compost is ready, remove from the ring and heap as a cone (10).
- Leave the heap undisturbed for 2 to 3 hours to allow the earthworms to move down the heap slowly.
- Separate the upper portion of the heap (11).
- Sieve the lower portion of the heap to separate the earthworms which can be used again for preparation of vermicompost (12).
- Pack the compost in bags and store these in a cool place.

Repeat process

About 20 days before removing the compost from cement rings place the organic waste, rock phosphate, and cowdung slurry in layers in another set of rings. Follow the step-wise procedure and use the earthworms separated from the compost as mentioned above.

Materials required

Materials required for vermicomposting in one cement ring (90 cm diameter × 30 cm height) or in a pit/walled enclosure (1.5 m × 1 m × 1 m):

	Cement ring	Pit/tank
Dry organic wastes (DOW)	50 kg	400 kg
Cowdung slurry (CS)	15 kg	120 kg
Rock phosphate (RP)	2 kg	16 kg
Earthworms (EW)	500–750	4000–5600
Water (W)	5 L every three days	40 L every three days
Ratio of DOW:CS:RP:EW:W	5:1.5:0.2:50–75:0.5	

The weights for all the ingredients except EW are expressed in kg.

Precautions

- Use only plant materials such as vegetable peelings, leaves, or grass.
- Remove glass, metal, and plastic materials from the organic material.

Usage

Vermicompost can be used for all crops (agricultural, horticultural, ornamental, and vegetable) at any stage of the crop.

Dosage

- For general use in agriculture, 3–4 t ha^{-1}.
- For fruit trees, 5–10 kg per tree.
- For vegetables, 3–4 t ha^{-1}.
- For flowers, 500–750 kg ha^{-1}.

Application

- For agricultural crops: Apply vermicompost by broadcasting when the seedlings are 12–15 cm in height and water the plants normally.
- For flowers, vegetables, and fruit trees: Apply vermicompost around base of the plant, cover with soil, and water regularly.

Advantages of Vermicompost

- Contains valuable nutrients [N (1–1.5%), phosphorus (P) (0.8%), potassium (K) (0.7%), micronutrients], enzymes, plant hormones, and antibiotics required for plant growth.
- Promotes fast growth of plants and increases crop yields.
- Increases the quantity and improves the quality of fruits, vegetables, and flowers.
- Maintains humus content of the soil.
- Increases water-holding capacity of the soil.
- Easy to produce and incurs low cost.
- Reduces salinization and acidification.
- Reduces soil erosion.
- Reduces pest attack.

Conclusion

By applying vermicompost in the fields, soil physical, chemical, and biological properties will be improved. Vermicompost application will also help in higher yields with improved grain quality.

On-farm Generation of N-rich Organic Material

S P Wani and M S Kumar

Soils in the tropics are low in organic matter content and have low nutrient supplying capacity. Soil organic matter plays an important role in crop production. To maintain or increase organic matter content regular application of organic materials such as farm compost, farmyard manure, and plant residues is needed. However, short supply of organic manures and competitive uses of farm residues as feed and fuel makes it difficult to apply to soil at desired levels. Fast-growing and nitrogen (N)-fixing trees such as *Gliricidia sepium* play an important role in tropical farming systems and are grown as green manure and shade trees, and for fodder and fuel. Growing *Gliricidia* plants on farm bunds serves dual purpose of producing N-rich organic matter under field conditions and also helps in conserving soil through reduced soil erosion. *Gliricidia* has fast growth, N-rich leaves, tolerance to pruning, ability to coppice vigorously, and good fodder value. It can be grown on bunds as rainfed plants even at places which receive only 500 mm rainfall annually.

The steps for growing *Gliricidia* are given below:

- *Gliricidia* can be established through cuttings which are taken from stems of at least one-year-old plants and have a minimal length of about 50 cm.
- In rainy season (July–August) cuttings can be planted under humid conditions in the soil in 10–15 cm deep holes.
- The stake method is simple, but suitable mainly for situations where only a few trees are to be established, such as for fence posts.
- For establishing large number of plants, seed propagation method is the most convenient and reliable means of establishment.
- Seeds should be soaked in water for 8–10 hours or overnight. The soaked seed can be planted in small plastic bags filled with soil and watered regularly.
- Alternatively, seeds should be immersed in concentrated sulfuric acid (H_2SO_4) for one minute. Then the acid should be poured out carefully and the seeds should be washed with running water for 3–4 hours. Treated and thoroughly washed seeds can be planted in small plastic bags filled with soil and watered regularly.
- Three to four-month-old seedlings can be planted on bunds in the rainy season at 50 cm spacing.
- One year after planting, harvesting can be started by lopping the plants at 0.75 m length above the ground. Green matter (leaves and tender stems) are separated from firewood. The tree prunings can be applied to the soil surface as mulch or incorporated as green manure.
- Lopping is done at 3–4 month intervals and 3–4 times per year.
- *Gliricidia* plants can be managed well through pruning at appropriate times (e.g., before planting rainy and postrainy season crops) so that nearby crop rows are not adversely affected.
- When plants are established, from first year onwards loppings from 700-m long bunds provide about 45 kg N ha^{-1} yr^{-1} (equivalent to 100 kg urea). Along with N, phosphorus, potassium, and other plant nutrients are also added back to the soil.

Integrated Pest Management

G V Ranga Rao and V Rameshwar Rao

Farmers in Andhra Pradesh, India cultivate several crops of which rice, sorghum, maize, cotton, pigeonpea, mung bean, chickpea, and groundnut are grown in vast areas. These crops are cultivated either as sole crops or intercrops. Insect pests and diseases are the major constraints to crop production. In India, the crop loss due to pests and diseases alone is 20–30%. The estimated annual crop loss is about Rs 115,000 million despite use of 0.1 million t of pesticide (active ingredient). Among several crop pests, *Helicoverpa*, *Spodoptera,* and white flies are important. The estimated loss due to *Helicoverpa* alone is about Rs 13,800 million in India. In some areas farmers spray pesticides 25 to 40 times on crops such as cotton and chili. Sometimes irrespective of several sprays of pesticides, crop losses are inevitable. Excessive usage of pesticides on crops for the past 30 years has led to the following problems:

- Several pests have developed pesticide resistance.
- Natural enemies are being badly affected.
- Minor pests have now become dominant causing severe damage to crops.
- Environmental pollution has become more persistent.
- Inputs for cultivation have increased enormously.

Adopting integrated pest management (IPM) options is the only solution to address these problems.

What is Integrated Pest Management?

The basic concept of IPM is the containment of a pest below economically damaging levels, using a combination of all feasible control measures. The following are the primary components of IPM:

- Effective monitoring using pheromone traps (whereever possible).
- Host plant resistance.
- Manipulation of the farming system to minimize pest infestation or damage.
- Enhanced natural control process.
- Selective use of bio-rational and/or synthetic pesticides.

Monitoring

Sex pheromones are used to monitor populations of a number of pest species including *Helicoverpa* spp and *Spodoptera* spp. A pheromone trap consists of a synthetic pheromone impregnated to a septum, usually of rubber or polyethylene, and placed in a trap. Traps can be of different shapes or colors, and placed at heights based on insect activity and crop architecture. Pheromones are specific to individual insects, saving time in the sorting and identification of the seizure. Pheromone traps cannot control crop pests. But the data obtained from these traps helps predict infestations and assists in the timely use of control measures.

Pest Resistant Cultivars

ICRISAT has developed cultivars resistant to pests and diseases in sorghum, pearl millet, groundnut, pigeonpea, and chickpea as given below:

- Sorghum cultivars resistant to shoot fly, stem borer, and head bug.
- Pearl millet cultivars resistant to smut.
- Groundnut varieties resistant/tolerant to sap sucking insects, leaf spots, and bud necrosis.
- Pigeonpea cultivars tolerant to *Helicoverpa* and fusarium wilt.
- Chickpea cultivars resistant to fusarium wilt and root rots.

By choosing and adopting the cultivars resistant to insect pests and diseases farmers can avoid crop losses with minimum usage of pesticides.

Cultural Control Methods

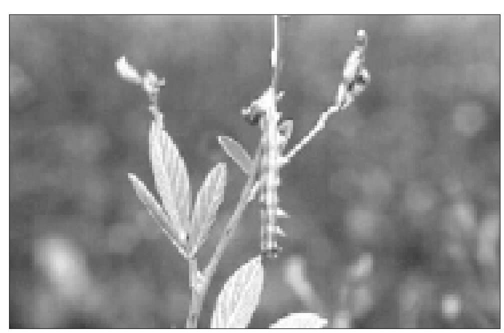
Another major component of an IPM program is cultural control. Farming systems can be manipulated in various ways. These options include early or delayed sowing, selection of intercrops, altering plant density or arrangement, and sowing genetic mixtures to reduce the impact or severity of insect pests. These options are location-specific and must be designed to suit local practices and customs. Some examples are given below:

- Intercropping coriander with chickpea may provide nectar sources for adult parasitoids improving natural control of *Helicoverpa* in chickpea.
- Castor or sunflower attracts *Spodoptera* when intecropped with groundnut and thus reduces the pest infestation on groundnut.
- Manually shaking pigeonpea plants helps dislodge *Helicoverpa* larvae when heavy infestation occurs.
- Aphid or jassid infestations can be minimized by growing mung bean or cowpea as an intercrop or border crop with cotton.

Increasing the Natural Control Process

All pests present on crops are not harmful. There are several “farmer-friendly” pests which live on crop pests. These pests can be categorized into three groups: parasites, predators, and pathogens.

Predators hunt and consume all or part of their prey; e.g., spiders, lady-bird beetles, dragon flies, and insectivorous birds. Parasitoids live on or in the body of their host. Many parasitoids have been reported to feed on *Helicoverpa* and *Spodoptera*. Parasitoids can be mass-reared and released into an infested field. In addition, a number of commercial companies are marketing parasitoids, the most common being the egg parasitoids, *Trichogramma* spp which attack eggs of *Helicoverpa* and other lepidopterans. Among insect pathogens that cause severe mortality, viruses are important. Of viruses that kill pests, the nuclear polyhedrosis virus (NPV) is the most prominent.



The following actions are necessary to increase natural enemies in crop fields:

- Install bird perches in the field to attract predatory birds (egrets) which prey on insect pests.
- Irrigate groundnut fields during the day; *Spodoptera* larvae will come out of the soil and are eaten by birds.
- Avoid indiscriminate spraying of synthetic pesticides.
- Encourage the use of eco-friendly bio-rational and synthetic pesticides to save natural enemy populations.
- Organic pesticides should be sprayed judiciously only after assessing the pest and parasitoid densities in the field.

Bio-rational and synthetic pesticides

There are many bio-rational and synthetic pesticides that are commercially available to farmers. Bio-rational pesticides contain biologically active products such as plant derived products, hormones, microbial agents (*Bacillus thuringiensis*, NPV), pathogenic fungi, etc. These products are usually safe for human beings and for the environment. Among various bio-rational products, neem and NPV are popularly used in plant protection. These products are commercially available to farmers. Farmers can produce their own high quality bio-rational products at minimum cost.

Preparation of neem seed extract

- Collect fresh, good quality neem fruit and dry them under shade.
- Powder the dried fruits.
- Soak the powder in water overnight before use (1 kg powder in 5 L of water).
- Filter the neem powder solution through fine cloth.
- Add 2–3 g of detergent as sticker to 1 L of the solution.
- Spray the solution on plants to control insect pests. To spray 1 ha of cotton or pigeonpea crop, 25 kg of neem powder mixed in 500 L of water is required. To spray 1 ha of groundnut or chickpea crop, 12.5 kg of neem powder in 250 L of water is sufficient.

Preparation of *Helicoverpa* nuclear polyhedrosis virus (HNPV) solution

- Collect healthy fourth instar larvae, 1–1.5 cm long from the field.
- Prepare the inoculum using 5 ml HNPV stock solution on 500 chickpea seeds that have been presoaked for 12 hours.
- Place 2–3 inoculated chickpea seeds in each container with a larva.
- Change the food on third day.
- Collect the dead larvae (normally 5 days after inoculation) and keep it in the refrigerator.
- Homogenize dead larvae in a blender with distilled water, if necessary.
- Filter the mixture through muslin cloth.
- Centrifuge for about 15 minutes at 5000 rpm.
- Discard the supernatant liquid and preserve the virus-containing sediment.

- Check the quality using a haemocytometer.
- Preserve the viral solution in a refrigerator.
- Spray the solution during late afternoon only because viral cells die due to ultra-violet (UV) rays which are more prominent in the morning.
- Mix the UV protectant (Robin blue®) at 1 ml per liter of spray solution at the time of application to protect the viral cells from UV light.
- Spray at 250 larval equivalents (LE) per ha on chickpea and groundnut, and at 500 LE per ha on pigeonpea and cotton using sufficient water for spraying [100 LE = 6 × 1011 polyhedral ocular bodies (POB); one fifth or sixth instar infected larva contains 3 × 109 POB).

If pest incidence persists, in spite of applying all the above methods then use synthetic pesticides. There are numerous synthetic pesticides available in the market. Farmers should contact local extension personnel for approved compounds, dosage, timing, and precautionary information.

Precautionary measures

Farmers can adopt the following precautionary measures while using pesticides:

- Do not buy prohibited and highly poisonous pesticides.
- Do not keep pesticides inside the house within the reach of children and domestic animals.
- Use recommended dosage of pesticides because natural enemies and crops will get affected with increased dosages.
- Do not use household utensils for preparing the pesticide solution.
- Use protective clothing and guards while spraying especially to cover hands, face, and eyes.
- Do not eat or smoke while spraying.
- Destroy or discard appropriately empty tins or bottles of pesticides because of possible danger of recycling and usage in households.

Integrated Pest Management Program

The IPM program includes several options. Some examples are given below:

- Seed treatment with fungicides (Bavistin, Thiram, Dithane M-45) before sowing.
- Use of tolerant/resistant varieties for insect pests and diseases in endemic areas.
- Following optimum plant spacing based on the duration and growth habit of the variety.
- Installation of *Helicoverpa armigera* pheromone traps at the time of sowing for intensive monitoring and planning control strategies.
- Intensive weed management in the early stage of the crop.
- Fixing of bird perches after crop establishment.
- Application of 5% neem fruit powder extract at flower initiation of pulse crops.
- Application of HNPV at 500 LE per ha for pigeonpea and 250 LE per ha for chickpea at peak oviposition phase and repetition of the same after 15–20 days in case of fresh oviposition.
- Manual shaking of pigeonpea plants to dislodge *Helicoverpa* larvae, and handpicking and destruction of larvae in chickpea during severe outbreak of the pest.
- Cautious application of appropriate chemical pesticides, if the options recommended above do not control pest population below levels of economic damage.

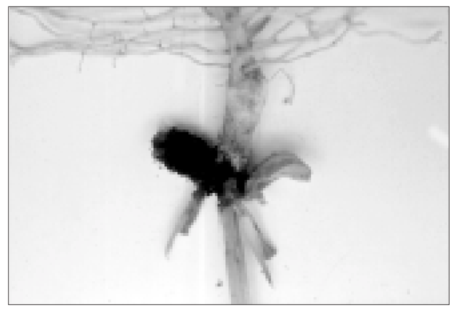
Fungal and Viral Diseases of Groundnut, Chickpea, and Pigeonpea and their Control

S Pande and J Narayana Rao

Groundnut

Soilborne diseases

Aspergillus crown rot ***(Aspergillus niger)***
The fungus causes both seed and seedling rot and drastically reduces the plant stand. Seeds may be attacked by the fungus leading to pre-emergence rotting. The rotting seeds are usually covered with black masses of spores. The emerged seedlings show rapid wilting of the entire plant or one or more branches especially during dry weather. The affected tissue becomes necrotic and is covered with black spore mass.

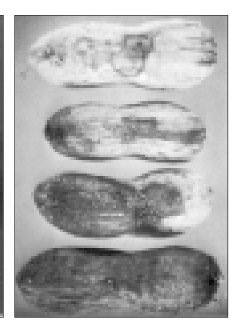


Control measures: Remove and destroy infected host debris of the previous season. Also seed treatment with Thiram, Captan, or Difolatan at 2.5 g kg^{-1} seed gives good control.

Stem and pod rot (***Sclerotium rolfsii***)
The fungus attacks the plants at the collar region and causes rotting of the whole plant or few lateral branches. White mycelium is seen around the affected stems. Pegs and pods are also attacked; pods become detached and are left in the soil at harvest. The mycelium produces abundant spherical sclerotia in the absence of organic food base.

Control measures: Cultivars resistant to stem and pod rot are not available. Cultural practices like deep plowing, sanitation, and control of leaf spots to prevent leaf drop helps in controlling stem rot. Seed treatment with Rizolex or Captan at 2.5 g kg^{-1} seed reduces stem rot incidence.

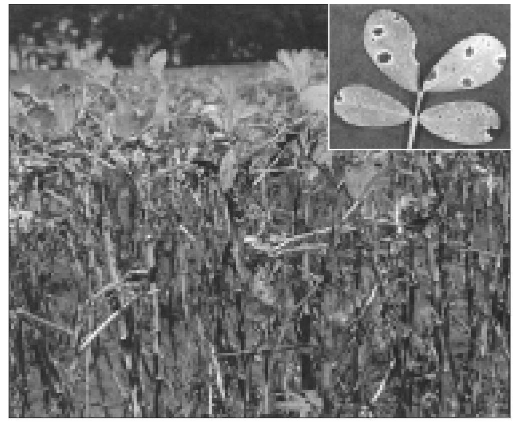
Rhizoctonia rot (***Rhizoctonia solani)***
The fungus causes pre- and post-emergence damping-off resulting in seedling mortality. In emerged seedlings, it causes root rot with dark brown lesions on the hypocotyl just below the soil surface. In adult plants it also causes peg and pod rots. Infected pods become discolored and vary from brown to black; the pods rot or wither.



Control measures: Avoidance of excess moisture in the soil and seed treatment with Thiram, Captan, or Dichloran at 2.5 g kg^{-1} seed provides good control.

Foliar diseases

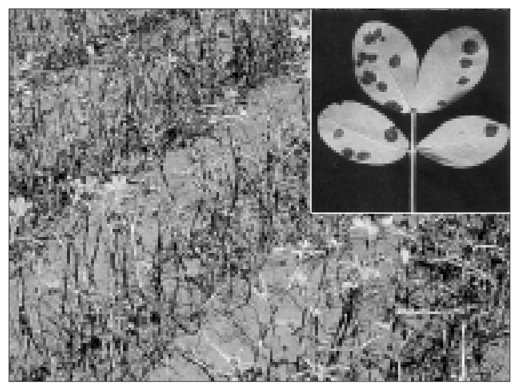
Early leaf spot (***Cercospora arachidicola***)



Lesions are sub-circular and brown to dark brown on the upper surface of the leaf. A yellow 'halo' commonly appears around the lesion on the upper surface. The fungus causes severe defoliation in cultivated local groundnuts. It sporulates on the upper surface of the leaf. Spots with irregular shape can develop on petioles and stems.

Control measures: Deep burial of infected debris of the crop from the previous season helps in reducing the disease. Depending on maturity group, one or two fungicidal sprays at 60–65 and 75–80 days after sowing with Bavistin at 1 g L^{-1} water or Kavach at 2 g L^{-1} water controls early leaf spot. High levels of resistance to early leaf spot are not available. But cultivars having moderate resistance are available; e.g., ICGs 1703, 6284, 7340, 9294, 10010, 10040, 10900, and 10946.

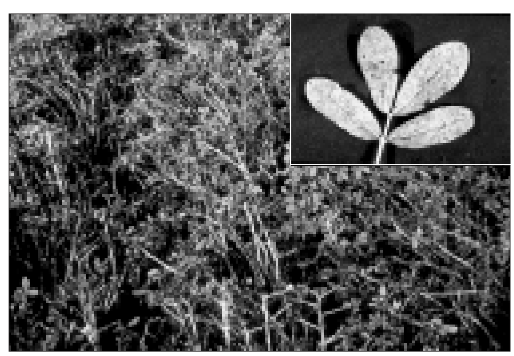
Late leaf spot (***Phaeoisariopsis personata***)



The leaf spots are nearly circular and darker and commonly without yellow halo. The fungus sporulates on the lower surface of the leaf. It causes severe defoliation.

Control measures: Deep burial of infested debris of the crop from the previous season helps in reducing the disease. Depending on the maturity group one or two fungicidal sprays with Bavistin at 1 g L^{-1} water or Kavach at 2 g L^{-1} water at 60–65 and 75–80 days after sowing controls the disease. Cultivars that are highly resistant to late leaf spot are not available in cultivated groundnuts. Cultivars with moderate resistance to late leaf spot are available; e.g., ICGs 1703, 6284, 7340, 9294, 10010, 10040, 10900, 10946; and ICGVs 86699, 92020, 92093, and 94080.

Rust (***Puccinia arachidis***)



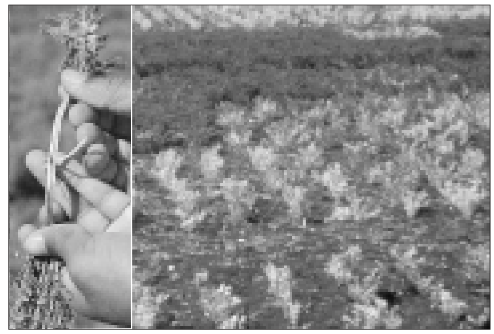
Orange colored pustules appear on the lower surface of leaves. The pustules are usually circular and range from 0.5 to 1.4 mm in diameter. The infected leaves become necrotic and dry up and tend to remain attached to the plant. Rust may cause pods to mature 2–3 weeks early and reduce the seed size.

Control measures: Remove and destroy volunteer plants as these plants harbor the rust inoculum during the off season. Depending on the maturity group one or two fungicidal sprays at 60–65 and 75–80 days after sowing with Calixin at 0.5 ml L^{-1} water or Kavach at 2 g L^{-1} water controls rust. High levels of resistance to rust are available; e.g., ICGs 1703, 6284, 7340, 9294, 10010, 10040, 10900, and 10946; and ICGVs 86699, 92020, and 92093.

Chickpea

Soilborne diseases

Wilt (***Fusarium oxysporum*** f. sp ***ciceris***)



Chickpea wilt appears within 25 days after sowing in a susceptible cultivar. The affected seedlings collapse and lie on the ground. These seedlings retain their dull green color. Adult plants show typical wilt symptoms of drooping of petioles, rachis, and leaflets. The roots do not show any external rotting, but when split vertically, brown discoloration of internal xylem is seen.

Control measures: Where land is not limiting, avoidance of planting in infected fields can minimize yield losses. Crop rotation with non-host crops (other than lentil, pea, pigeonpea) for more than 6 years helps in reducing wilt. Deep plowing during hot summer months and removal of infected host debris from the soil reduce wilt incidence. Seed treatment with Benlate T at 1.5 g kg^{-1} seed completely eradicates the seedborne fungus. About 160 resistant lines have been developed; e.g., ICCs 11315, 12241, 12237, 12269, 12428, and 14440.

Dry root rot (***Rhizoctonia bataticola***)

The disease generally appears around flowering and podding stage of the crop. The first symptom of the disease is yellowing and sudden drying of the plants. The tap root becomes dark brown, quite brittle in dry soil, and devoid of lateral roots. The fungus produces dark brown or black sclerotia on infected dead tissue.

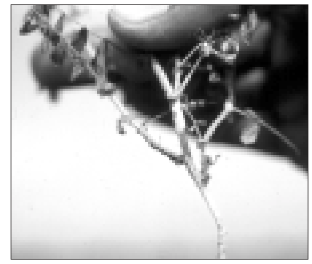
Control measures: Deep plowing during hot summer months and removal of infected host debris from the soil reduce the disease. Early sowing using early maturing cultivars is recommended to escape the disease during hot weather. Seed treatment with Captan or Thiram at 2.5 g kg^{-1} seed eradicates the seedborne fungus. Several cultivars with combined resistance to both wilt and dry root rot have been developed; e.g., ICCs 11315, 12241, 12257, 12268, 12270, and 12271.

Collar rot (***Sclerotium rolfssi***)

Collar rot is generally observed when soil moisture is high and temperatures are warm in the seedling stage. The incidence of collar rot decreases with increase in the age of the crop. Affected seedlings turn yellow and die. The seedlings generally collapse and show rotting at the collar region and below. The rotten portion is covered with whitish mycelial strands.

Control measures: Removal of undecomposed debris of the previous crop and plowing/deep plowing during hot summer months reduce collar rot incidence. Seed treatment with Rizolex or Rizolex + Thiram or Captan at 3 g kg^{-1} seed controls collar rot incidence.

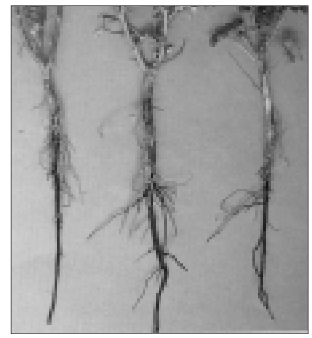
Wet root rot (***Rhizoctonia solani***)



The disease occurs in the seedling stage when there is high soil moisture and warm temperature. Seedlings do not usually collapse. A distinct dark brown lesion appears above the collar region on the main stem and can extend to lower branches in older plants. The stem and root portions below the lesion show rotting.

Control measures: Removal and destroying of crop debris reduces wet root rot incidence. Seed treatment with Captan or Thiram at 2.5 g kg^{-1} or Benlate at 3 g kg^{-1} seed controls wet root rot incidence.

Black root rot (***Fusarium solani***)

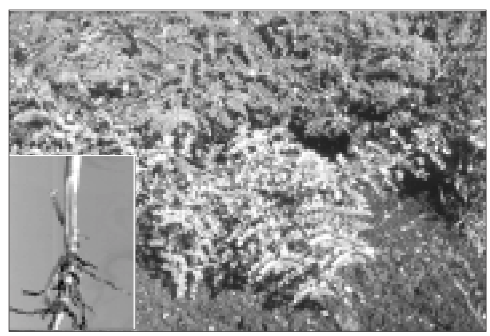


The disease can occur at any stage of the crop. Affected plants turn yellow and wilt. Roots of the affected plants rot and turn black. Excessive moisture and moderately high temperature encourage disease development.

Control measures: Removal and destroying of crop debris and seed treatment with Thiram + Benomyl or Thiram + Captan at 2.5 g kg^{-1} seed control black root rot incidence. Several resistant lines have been developed; e.g., ICCs 11313, 11316, 11317, 11320, 11324, 12236, and 12239.

Viral disease

Stunt

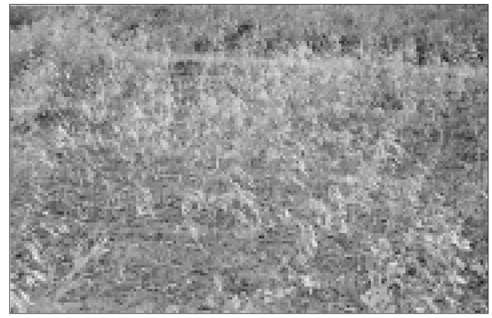


Affected plants can be easily spotted in the field by their yellow, orange, or brown discoloration and stunted growth. The leaflets of the affected plants are small and yellow, orange, or brown in color. The stems and leaves of diseased plants are stiffer and thicker than normal. The diseased plants show typical phloem browning.

Control measures: Close spacing between plants reduces stunt incidence. Sowing should be done when the aphid vector activity is low.

Pigeonpea

Soilborne diseases



Phytophthora blight (***Phytophthora drechsleri*** f. sp ***cajani***)

The fungus attacks young plants and causes total mortality. Infected leaves show water-soaked lesions and loose turgidity and then become desiccated. Brown to black lesions appear on stems and petioles. When these lesions girdle, the main stem and branches break. Excess soil moisture, humid and cloudy weather, and temperature around 25°C are favorable for infection and disease development.

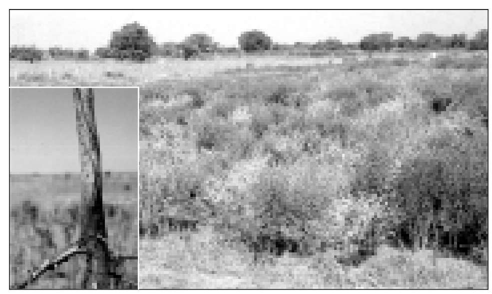
Control measures: Removal and destroying infected debris of the previous crop from the field reduces disease incidence. Planting on slightly raised beds to avoid waterlogging helps in managing the disease. Seed treatment with Metalaxyl (Ridomil) at 3 g kg^{-1} seed or seed dressing followed by two foliar sprays with Metalaxyl at fortnightly intervals starting from 15 days after sowing provides good control. Some of the resistant cultivars are ICPL 150, ICPL 288, ICPL 304, KPBR 80-1-4, and Hy-4.

Collar rot (***Sclerotium rolfsi***)

Collar rot normally appears in the seedling stage. It causes rotting at the collar region resulting in death of the seedlings. Dead seedlings show white mycelial growth at the collar region. The disease is more common when un-decomposed organic matter is left on the soil surface. High soil moisture and temperature at sowing encourages the disease.

Control measures: Cultural practices like removal of debris of the previous crop and deep plowing during hot summer months reduce the disease incidence. Seed treatment with Captan at 2.5 g kg^{-1} seed or Rizolex alone or Rizolex + Thiram at 3 g kg^{-1} seed controls collar rot incidence.

Fusarium wilt (***Fusarium udum***)



The fungus infects the plant through root hairs and colonizes the vascular system causing brown to black discoloration of xylem, yellowing of leaves, and death of the plant. A typical purple band is seen on the stem and lower branches of infected plants. The purple band on the stem is not visible on young wilted plants but internal xylem browning is clearly visible. The disease is more severe during flowering and podding stage and is more in black soils (Vertisols) than in red soils (Alfisols).

Control measures: Collecting and burning of wilted plants from the field and crop rotation with non-host crops for more than three years eradicate the fungus from the soil. Seed treatment with Benlate T at 2 g kg^{-1} seed completely eradicates the seedborne inoculum of the fungus. Several lines with resistance have been identified; e.g., ICP 8863, ICP 9145, ICPL 267, AL 1, BDN 2, and DL 82.

Dry root rot (***Rizoctonia bataticola***)

The disease normally appears at flowering and podding stage and is favored by high temperatures and dry weather. Infected plants dry suddenly and prematurely. The lateral roots are mainly affected and have black streaks with dark brown to black sclerotia underneath the bark. The tap root is very brittle.

Control measures: Late sowing should be avoided so that the crop escapes from drought and high temperatures. Some of the resistant cultivars are ICPLs 86005, 86020, 87105, and 91208.

Viral disease

Sterility mosaic

The disease is caused by a virus and is transmitted by the eriophyid mite *Aceria cajani*. It is identified in the field as patches of stunted, bushy, pale green plants without flowers and pods. The leaves of the infected plants are small and show a light or dark green mosaic pattern. The pathogen and the vector survive in summer pigeonpea during the off-season.

Control measures: Avoiding pigeonpea cultivation in the off-season is the best way to control the spread of the disease. Crop rotation with crops such as sorghum increase the disease incidence. The disease can be controlled by spraying insecticides and acaricides but their use is not economical. Several cultivars with resistance have been identified and some of them are DA 11, DA 13, ICPL 86, ICPL 146, ICPL 87051, PDA 2, and PDA 10.

About ICRISAT

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, chickpea, pigeonpea and groundnut – five crops vital to life for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research that can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

ICRISAT was established in 1972. It is supported by the Consultative Group on International Agricultural Research (CGIAR), an informal association of approximately 50 public and private sector donors. It is co-sponsored by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP), and the World Bank. ICRISAT is one of 16 nonprofit CGIAR-supported Future Harvest Centers.

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