

MODERN CONCEPTS OF AGRICULTURE

Integrated Crop Management

Dr Dinesh Kumar
Senior Scientist
Division of Agronomy
Indian Agricultural Research Institute
New Delhi-110012

Dr Y.S. Shivay
Senior Scientist
Division of Agronomy
Indian Agricultural Research Institute
New Delhi-110012

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Keywords

Integrated Crop Management, ICM, Integrated Pest Management, IPM, Integrated Disease Management, IDM, Integrated Weed Management, IWM, Integrated Nutrient Management, INM, Seedling Establishment, Cultural Practices, Rice

The systems of cropping developed since the Vedic times in India and the pre-Christian era in the West adopted principles of matching climate, crops and seasons. This enabled the prolongation of the growing period, and could be considered the beginning of methodical development of cropping systems. Crop residues were incorporated thereby adding the much-required organic matter to maintain soil biological activity. Intensification of agriculture moved away from these systems due to the development of species and varieties with high harvest indices. Current research highlights the need to adopt these ancient methods practised by farmers. Hence, emphasis is placed upon increasing biodiversity of agricultural systems and soils through the integration of either crops alone, crops and trees, crops and green manures, or even crops and animals.

Historically, agricultural growth and increases in agricultural productivity have been a prerequisite for sustained economic growth and development. Today agriculture remains an important if not dominant part of most developing countries' economies, and is the most likely source of significant economic growth and reduction in poverty. Moreover, agriculture - and related rural enterprise - is a livelihood strategy for hundreds of millions of the world's poorest people and can have a major impact on the environment. Well-managed, agriculture can enhance livelihoods, conserve soil and water resources, preserve trees and biodiversity, and contribute to the locking of carbon. Badly-managed, it can lead to food insecurity, environmental degradation and pollution, depletion of natural resources, contaminated food, and poor nutrition and health.

In developing countries, more than a quarter of potential food and fibre crop yield is routinely lost to pests, weeds and diseases. It is increasingly apparent that minimizing the damage caused by these organisms in a sustainable manner is not something that can be achieved in isolation from the whole farming system in which the crops are produced. Among the challenges are:

- the development of integrated crop management (ICM) systems for pests, diseases and weeds, which are environmentally sustainable and socio-economically appropriate,
- countering the misuse and overuse of synthetic chemical pesticides, promoting their safe disposal, and developing pest management systems based on newer safer chemicals,
- developing alternative pest-control technologies based, for example, on insect pathogens, insect pheromones and plant allelochemicals, and
- using participatory approaches for the development and extension of integrated crop management technologies and strategies.

The most significant development in pest control occurred in the 1940s with the introduction of the organochlorine insecticides such as DDT. This group provided highly effective control with relatively low mammalian toxicity and at single stroke removed the problem of pests from many crops and where pests had provided the major limitation and this enabled greater intensification and specialization. Subsequent developments of both selective and non-selective herbicides and the ability to produce unlimited quantities of nitrogenous fertilizers from oil and gas resources removed weed control and nutrient supply as restrictions to yield. The result of these technologies has been a perpetual increase in world food supplies. This intensification of production has not been without cost or problems. The effectiveness of the organo chlorines in controlling pests meant that farmers were able to abandon the multiple control mechanisms

formerly used in favour of one single mechanism. The widespread and indiscriminate use of chemical insecticides led to some pest and weed species developing resistance. Resistance problems initially were managed by substitution where an active ingredient was replaced by another with a different mode of action. However, where resistance was widespread this simply meant over-use of the alternative compound with predictable results. Hence, there is need to develop/utilize crop management strategies that cause very little environmental pollution. Management of crops in an integrated manner could be quite useful in this direction.

Concepts and Definitions

Integrated Crop Management (ICM) is a common sense approach to farming. It combines the best of traditional methods with appropriate modern technology, balancing the economic production of crops with positive environmental management. It is based on understanding the intricate balance between our environment and agriculture and is a whole-farm approach in achieving a proper balance. Basic components of ICM are crop management, nutrient management, pest management, and financial management. Each of these components of ICM is associated with agricultural Best Management Practices (BMP). Each BMP overlaps between the broader components of ICM. The relationship between farm management and BMP implementation is very dynamic. For instance, crop rotations can be used for reduced erosion and nutrient mobility, increased pest prevention, and better nutrient balancing through the use of nitrogen fixing plants. Through the process of ICM, farmers make better use of on-farm resources. In the end, ICM and subsequent improved use of on-farm resources cause a reduced dependency on outside inputs of fertilizers, pesticides, and herbicides through the integration of farm management components and best management practices.

Integrated Crop Management can be thought of as a concept defining ideals and goals which then have to be 'translated' into definitions which can be implemented by farmers. Simply put, the concept is to integrate the management of individual crops in order to benefit from the interactions between them. In many respects integrating crop production strategies to provide benefits such as pest control, maintain soil fertility, etc. is an ancient technique. However, ICM also takes advantage of modern technology to improve on the system. Some definitions of ICM are given below:

- *"ICM is a method of farming that balances the requirements of running a profitable business with responsibility and sensitivity to the environment. It includes practices that avoid waste, enhance energy efficiency and minimize pollution. ICM combines the best of modern technology with some basic principles of good farming practice and is a whole farm, long term strategy".*

- *"ICM is an approach to farming which aims to balance production with economic and environmental considerations by means of a combination of measures including crop rotation, cultivations, appropriate crop varieties and careful use of inputs".*

ICM is a 'whole farm approach' which is site specific and includes:

- the use of crop rotations
- appropriate cultivation techniques
- careful choice of seed varieties
- minimum reliance on artificial inputs such as fertilisers, pesticides and fossil fuels

- maintenance of the landscape
- the enhancement of wildlife habitats

One of the main objectives of ICM is the reduction or replacement of external farm inputs, such as inorganic fertilizers, pesticides and fuel, by means of farm produced substitutes and better management of inputs. Total replacement is not possible without significant loss of yields, but partial substitution of inputs can be achieved by the use of natural resources, the avoidance of waste and efficient management of external inputs. This would then lead to reduced production cost and less environmental degradation and high biodiversity (Figure 1).

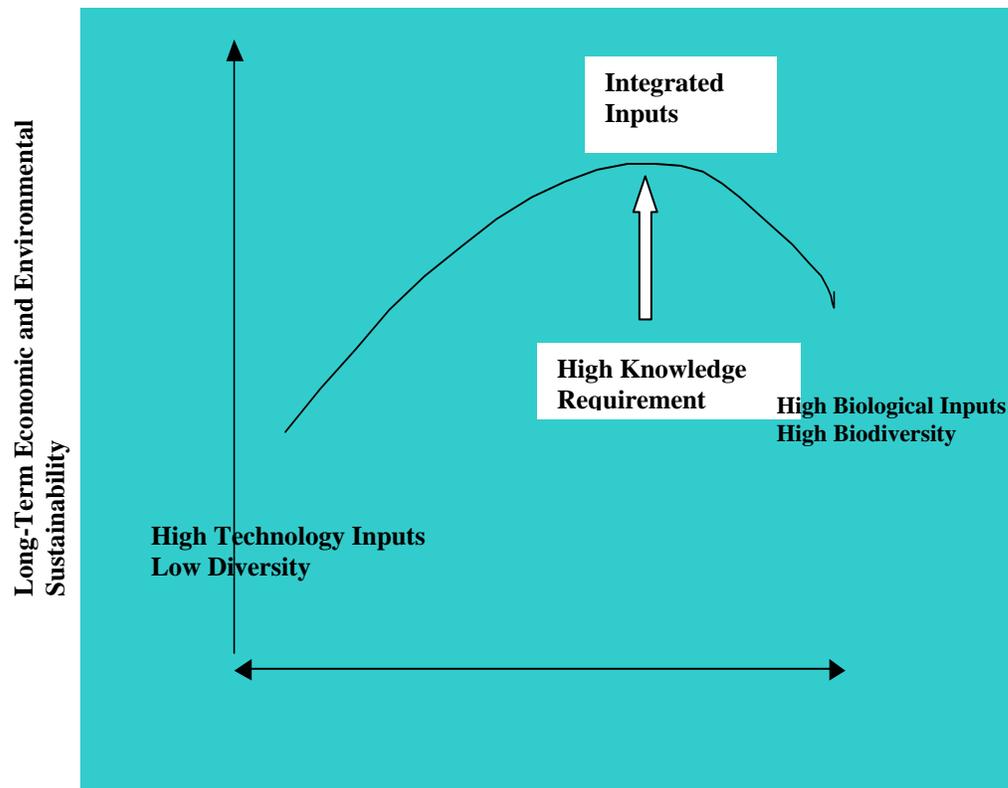


Fig. 1: The relationship between high technology input, low diversity systems and high biological input, high diversity systems and long-term environmental and economic sustainability in plant management systems.

Integrated Crop Management (ICM) can be thought of as a means of production which falls somewhere between conventional production and organic production. The concept of ICM can therefore be considered ultimately as a compromise between two different consumer demands:

- the demand for more environmentally friendly farming, especially the reduced use of plant protection products, and
- the demand for food to be safe, affordable to all, widely available, fresh and insect-free and perfect in shape and size.

Whilst conventional agriculture clearly meets the latter demand and organic the former, neither fully meets both. Although it is easy to state that ICM falls somewhere between conventional and organic production, it is considerably more difficult to define it precisely. Adding to the confusion is the use of the terms Integrated Production (IP) and Integrated Farming Systems (IFS), which can be used interchangeably, and Integrated Pest Management (IPM); compounding this is the concept of sustainable agriculture. The relationship between these terms and ICM is illustrated in Figure 2.

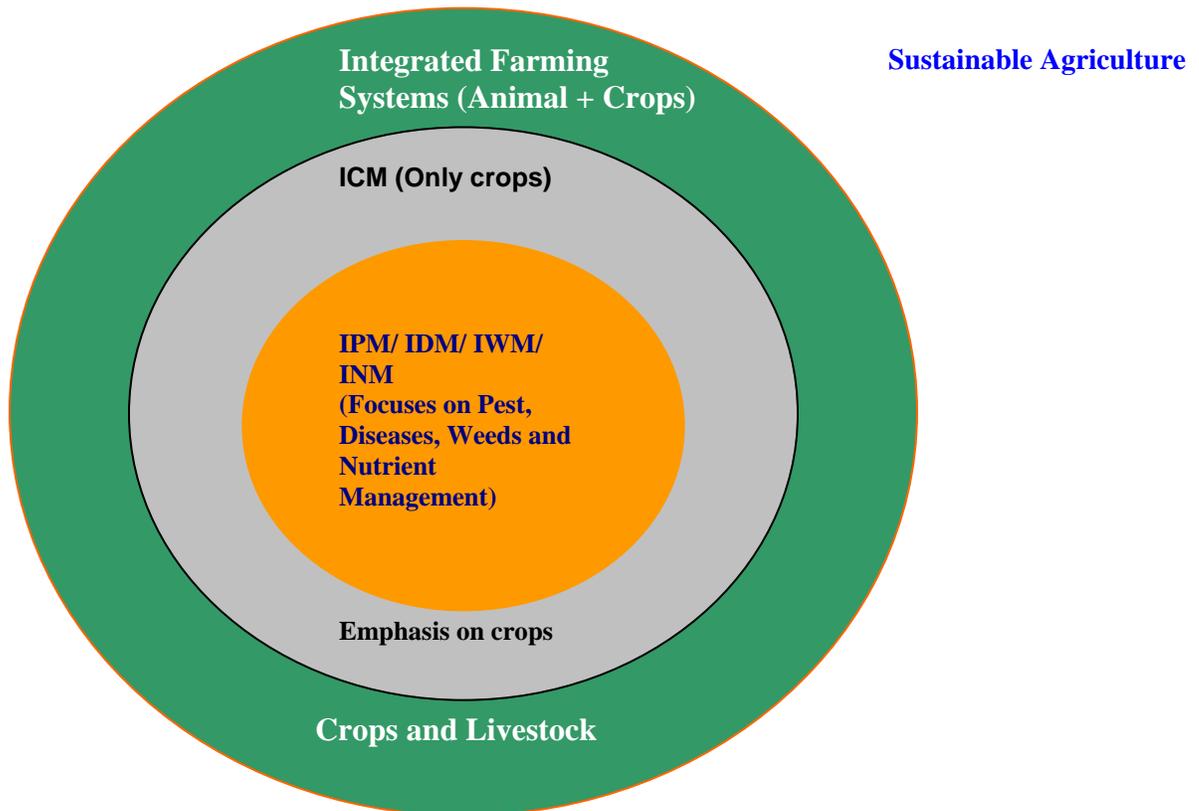


Fig. 2: Relationship between ICM and related terms

The most widely quoted concept of sustainable development is the World Commission on Environment and Development definition of 1987 which states that, 'Sustainable development is development that meets the needs of the present without compromising the needs of future generations to meet their own needs'. Harwood (1990) developed the following definition of sustainable agriculture, '*sustainable agriculture is a system that can evolve indefinitely toward greater human utility, greater efficiency of resource use and a balance with the environment which is favourable to humans and most other species*'. IFS/IP fit within this definition of sustainable agriculture and represents a whole farm approach to agricultural production where each individual enterprise is integrated with the others to produce benefits through their mutual interactions. IPM/ IDM/ IWM/ INM can be thought of as components of ICM focusing specifically on the pests, disease, weeds and nutrient management aspect, respectively, of crop production. ICM therefore encapsulates IPM and is in turn encapsulated by IFS/IP. Having said this, IFS is often used interchangeably with ICM. Technically, if livestock are present, IFS or IP should be used, if not, ICM is the appropriate term.

Despite the fact that ICM also emerged in response to perceived problems inherent in conventional agriculture the original underlying ideology is considerably less radical than organic production. Rather than being initially conceived as an alternative system to be operated instead of conventional farming, ICM has evolved to address perceived problems with conventional production from within the system by extending (sometimes significantly) and building on the concept of Good Agricultural Practice. In keeping with this placement, ICM production techniques are not as radical as organic prescriptions, although they may still involve considerable departures from conventional production practice for many farmers. Whilst in organic production chemical inputs are frowned upon and synthetic formulations prohibited, ICM views them as harmful only in excess and the response is to reduce their use rather than to ban them completely. Further, part of the rationale for reduced use is related to cost savings and/or maximizing input efficiency rather than solely environmental criteria. Whilst ICM does not seek to operate outside the current conventional food production and distribution system (both upstream and downstream), it does advocate modification to these systems. ICM may also necessitate the creation of new downstream agencies to monitor and verify quality assurance schemes. Differences between conventional agriculture, integrated crop management and organic agriculture are summarized in Table 1.

Table 1: Conventional Agriculture, Integrated Crop Management and Organic Agriculture

Particular	Organic Agriculture	ICM Systems	Conventional Agriculture
Practice Production techniques	Non-use of inorganic inputs. Emphasis on the sustainable use of resources and farm animal welfare.	Technologically intensive set of production techniques which emphasize equally environment, farm incomes and food quality.	Emphasis on the application of technology to increase yields, productivity and profits.
Knowledge requirement	Radical break with conventional farming knowledge networks. Requires the development of a new R&D and advisory system. Local/tacit knowledge base.	Demands new developments within the existing advisory system and more targeted R&D. Possible re-training needed if enterprise mix alters. Mix of local and external knowledge.	Traditional R&D and advice (public and private sectors). Standardized knowledge base.
Ideas underpinning practice	Initially a deliberate and radical critique of conventional methods of food production, marketing and consumption. Sustainable resource use for food production is key aim.	Environmental considerations given greater emphasis within food production. A relatively more sustainable use of resources for producing food than conventional agriculture.	Productivism through intensification, specialization and concentration.
Relationships within the food chain	Aims to draw consumers closer to producers. Potential for producers to exert more control within the food supply chain through alternative methods of marketing, price premiums.	IFS is in part a response to consumer concerns about production methods. Potential for consumers to be brought slightly closer to producers through labeling schemes based on IFS. Producers position in food supply chain slightly Improved e.g. through quality assurance schemes.	Consumers distant from producers. Producers occupy a potentially more marginal position within the food supply chain.

Adapted from: Morris, C. and Winter, M. (1999) *'Integrated farming systems: the third way for European agriculture?'* In: Land use policy 16 (1999), Pages 193-205.

Underlying Principles of ICM

Improving crop production quantity and quality taking into concern:

- Sustainability with regard to ecological and economic aspects
- Optimization of local resources and minimization of external inputs
- Environmental and human health as a central focus
- Integrating agro ecological, economic and human resource aspects, including local and science-based knowledge
- Emphasizing interrelatedness of various components, i.e. management practices in relation to crop conditions
- Requiring empowerment and collectivity at the farmer level relating to crop management needs assessment, decision-making and implementation.

Of course there can be no single 'blueprint' or ideal ICM system which would be appropriate to all conditions of climate, soil, prevailing market forces, and so forth. The aim is to establish principles, know-how and guidelines through which advisers and farmers can devise their own optimum ICM strategies. These can range between extremes of 'near-conventional' to 'near-organic' regimes. The ICM approach depends heavily on the development, testing and use of a range of new technologies. These include more selective chemical pesticides, more precise application systems, improved biological control methods, disease-resistant crop varieties, more reliable disease, pest, weed and nutritional forecasting and decision-support systems, rapid diagnostic methods for plant diseases, and establishment of habitats for natural enemies of pests.

Guidelines of ICM

The development of agricultural production has typically meant the concentration of a single species in a confined area. Rather than crop plants being treated as individuals the field is treated as a single population to suit activities such as sowing and harvesting. The following guidelines are a good beginning for effective crop production:

- proper planning includes marketing, production, pest management, and post harvest handling of the crop
- selection of production sites considering all aspects of production and pest management, including soil type and drainage, past pest problems, low areas, soil nutrients, and pH
- field scouting and crop problem identification includes pest activity, irrigation needs, and drainage problems, as well as general crop health and stage of production
- management action guidelines, depending on the intensity of management, cultivar, and the life stages of both the plants and the pests
- sprayer calibration and maintenance
- record keeping, including field history, pesticide and fertilizer applications, and key pests
- cost benefit analysis
- follow-up and review of management decisions after the production season to improve profitability

Major Components of ICM

1. Site and variety selection
2. Seed quality and health
3. Site, Crop Rotation and Varietal Choice
 - assess the effect of site features when selecting a crop rotation
 - consider the significance of the various factors influencing choice of rotation
 - appreciate the environmental impact of contrasting rotations
 - assess the effect of varietal choice and seed quality on achieving the aim of ICM
 - increase diversity of crop species to prevent disease and pest carry over from crop to crop
 - ensure effective nutrient uptake by scheduling crops with different nitrogen demands in the correct sequences
 - preserve soil fertility, structure and minimize erosion by ensuring adequate crop cover, good rooting depth and reduction of compaction
4. Soil Management and Crop Nutrition
 - reduced energy usage (i.e. fuel)
 - reduced soil erosion
 - reduce adverse effects on soil invertebrates such as earthworms and predatory beetles and spiders
 - cultivations dependent on soil type, climate and topography of individual farms
 - identify and assess soil properties in relation to agricultural management and for the prevention of soil erosion
 - appreciate the value and use of technology in planned cultivation systems
 - be aware of the factors to be taken into account for fertilizer management plans for a field situation
 - assess the environmental impact of management decisions and the policy adjustments required by legislation and Codes of Good Practice
 - appreciate the value and use of technology in water resource and irrigation management
 - evaluate the efficiency of operation and safety of a range of equipment
 - evaluate the suitability and legality of fertilizer storage and associated signs
 - understand the situation relative to phosphate and eutrophication
 - manage residues from previous crop to supply nutrients and reduce erosion
 - regular soil analysis for nutrient recommendation
 - use of cover crops/green manures to minimize leaching and erosion
 - Integrated Nutrient Management (INM): soil health, disorder analysis and improvement, fertilization
5. Crop Protection
 - appreciate the importance of crop monitoring in evaluating crop protection problems and in the design of integrated control strategies

- understand the value of existing information technology and expert systems used in crop protection decision making
- evaluate the consequences of pesticide application and the significance of reduced/restricted use and developments in biotechnology
- specify the conditions and procedures required for safe, accurate and economic application
- be familiar with techniques for the safe disposal of chemicals and their containers
- appreciate the requirements of legislation, Codes of Conduct and safe working practices
- minimal use of well selected pesticides, i.e. ones that have minimal off target effects
- in crop monitoring systems (such as traps) to assess pest levels to scale pesticide use to the level of the problem
- alternative husbandry techniques such as mechanical weeding. Improve habitat for predators to increase natural level of biological control
- Integrated Pest Management (IPM): prevention of pest outbreak, including insects, diseases, weeds and vertebrates, and sustainable management with emphasis on natural control
- Integrated Disease Management (IDM): prevention of disease outbreak and sustainable management

6. Wildlife and Landscape Management

- appreciate the inter-relationships between enterprises in a land use system
- understand the role of government and non-government organizations involved with conservation issues
- be aware of the factors which contribute to the conservation status of an area
- consider the criteria involved in selecting specially protected areas
- be aware of the agronomic benefits of conservation practices
- Hedges, ditches, field margins, beetle banks and conservation headlands allowing wild species to establish and migrate, and to provide recreational areas for people

7. Energy efficiency:

- detailed analysis of energy use, especially fossil fuels
- remedial action to minimize waste
- consider alternative energy sources
- change in cultivation practice, i.e. less passes
- replacement of high fuel consumption machinery, with more efficient alternatives
- rationalization of vehicle movements

Management Options for Reducing Crop Inputs

Strategies for reducing chemical input use can be placed on a continuum of increasing cropping system management: (i) efficiency in input use; (ii) crop management; and (iii) redesign of the cropping system to reduce reliance on inputs.

(i)Efficiency of inputs: Strategies to maximize efficiency of crop inputs include reduced tillage; reduced pesticide rates, using economic thresholds for pests, site-specific pest and soil management, use of models to predict pest occurrence and soil nutrient supplying power, and maximizing interactions between soil and crop management. Tillage reduction has provided significant savings in input costs, though it has also meant greater investment in seeding equipment. Economic thresholds (ET) were originally developed as tools for insect pest management and have subsequently been applied to weeds and diseases. The ET concept has been criticized on several grounds: ET's oversimplify the causes of yield loss (e.g., relative time of emergence of weed and crop not considered); most ET's only consider one pest-one crop interaction; ET's consider the impact of the pest for one year only; ET's consider only a apply/do not apply choice with no opportunity for reduced rate or alternative control measure; and ET's deal exclusively with direct pest management and therefore encourage reactive rather than proactive approaches. Herbicide use has been shown to be reduced using reduced herbicide rates, band application, using knowledge of weed emergence periodicity to optimize herbicide use, and site-specific management. Efficiency of fertilizer use can be maximized by greater knowledge of indigenous soil nutrient content (i.e., soil testing), better knowledge of N credits from legumes in rotation, and site-specific management.

(ii)Crop Management: Weed management strategies in a reduced input system include competitive crops, competitive cultivars, manipulating seeding dates, seeding at higher rates, choosing cultivars with enhanced mycorrhizal dependency, nutrient management, growing allelopathic plants and using in-crop tillage instead of herbicides to control weeds. The right time of sowing/transplanting, disease and weed management can help in achieving the better crop management.

(iii) Redesigning the Cropping System: A complementary longer-term strategy for preventative management involves redesigning the cropping system. The aim is to design cropping systems that can function effectively with fewer off-farm inputs. Since cropping systems are site-specific, it follows that design changes must also be site-specific. Among preventative strategies, crop rotation is one of the most important. Rotation of crops with varied planting dates, growth habits and fertility requirements will minimize the likelihood that pest will adapt to the cropping systems and proliferate. Crop rotation also enhances soil biological activity and fertility. Organic farmers rely heavily on crop rotation to maintain cropping system function, including management of weeds and maintenance of soil fertility. The role of crop rotation in reducing problems of weeds, diseases and in enhancing soil nutrient status has already been documented. Intercropping diversifies the cropping system spatially and can reduce weeds, diseases and insects. Cover crops are living ground cover planted into or after a main crop and are grown for their soil-conserving and weed suppressing abilities.

ICM Strategy and Approach

The strategy encompasses crops, soils, environment, climate change, production, and environmental economics. It is the integration of knowledge-based systems research to:

- enhance sustainability,
- find alternative methods for long-term soil and crop health which support and preserve soil, water, air and economic products of agriculture, increase the efficiency of nutrient and water flow among crop and livestock systems, enhance economic return and reduce

wastes through a more efficient conversion of inputs, natural or manmade, to economic product; capturing and holding more components of the system (carbon credits, biodiversity) and to reduce movement beyond the agricultural system (environmental risk),

- implement systematic approaches to deal with disease, weeds, and insects that are significant threats to crops and the crop/livestock interface that impact value-chains, increase genetic research and other technologies to reduce threats and enhance value chains.

The major components of ICM strategies and approaches, e.g. seedling establishment, integrated disease management (IDM), integrated pest management (IPM), integrated weed management (IWM) and integrated nutrient management (INM) are discussed below in detail:

1. Seedling Establishment: Maintenance of optimum plant population is the key for successful crop production. The manipulation of row spacing dimensions, plant populations, and the overall spatial arrangement of crop plants in a field can help in getting higher yield and quality of farm products. The crop canopy has often been manipulated by row spacing and population adjustments in an attempt to improve yields, production efficiencies, and profits. Similarly, plant breeders have altered plant architecture in an effort to improve light interception by crop plants. Seed quality (variety and seed lot, seed germination, vigour, seed size, green seed, etc) also affect the germination and establishment of crops. Seeds of better quality results in good crop establishment. Seeding practices (seeding depth, seeding date, seeding method, herbicide residues, seed treatments, fertilizer placement, surface residues, equipment settings, etc) influence crop establishment. Therefore, right time, method, spacing, seed rate and depth of sowing helps in achieving optimum plant population under field conditions.

2. Integrated Disease Management: The philosophy of integrated disease management is based on the assumption that populations of all organisms are in some kind of balance with their resources in each crop biosystem. If this balance is upset, it can be restored by manipulation in such a way as to achieve an acceptable level of control of damaging species without unduly harming the desirable flora or fauna or their physical environment. ‘Integrated Disease Management’ involves the selection and application of a harmonious range of disease control strategies that minimize losses and maximizes returns. The objective of integrated control programs is to achieve a level of disease control that is acceptable in economic terms to farmers and at the same time causes minimal disturbance to the environments of non target individuals. Integrated Disease Management can be considered at two levels. An integrated control program may be aimed at all of the diseases that affect a particular crop or an integrated control program may be developed for a specific disease that affects a crop. Disease Management Strategy can produce one of several desirable outcomes that may include:

- prevention or postponement of the introduction of a disease(s) that is not already present in the area
- reduction of the rate of build-up of a disease that has been introduced to the new area
- elimination of a disease that may be affecting profitability or minimization of the impacts of a disease on crop growth and/or productivity

Use of these Guidelines can therefore help to:

- identify those diseases present
- understand the basic principles of plant pathology and disease control
- apply general IDM strategies across the farm
- assess and monitor disease incidence and severity over time
- plan and program an effective IDM strategy for specific disease problems
- get help from those that can provide diagnosis and further information.

Efficient management of diseases affecting field crops principally involves the sowing of seeds of disease resistant crop varieties (where available and appropriate) and the employment of sound agronomic practices. Effective disease management must be integrated with management of the whole farm. Basic strategies should be implemented regardless of whether or not a significant disease problem exists. These basic strategies include the following:

- (i) conduct disease survey in each season
- (ii) practice farm hygiene principles
- (iii) use resistant varieties where available
- (iv) provide a balanced crop nutrition
- (v) manage crop residues to minimize carryover of pathogens into subsequent crops
- (vi) develop a sound crop rotation strategy
- (vii) use chemical and biological means to control diseases, if required

3. Integrated Pest Management: Today's economic constraints place increasing demands on agricultural producers to find ways to optimize the efficiency of crop protection. Pest control decisions must consider many factors, including the effects of control practices on the pest, beneficial and nontarget organisms, and the potential for developing pesticide-resistant pests. Crop protection decisions must also strongly consider the protection of farm workers, consumers, ground and surface waters, and the environment. To better meet these crop protection challenges, many farmers are using a highly effective approach called integrated pest management (IPM). IPM is a crop protection philosophy that effectively combines and uses short- and long-term production tactics that help optimize net profit while minimizing the risk of undesirable environmental and health effects. IPM bases crop protection decisions on timely, objective, and individualized information on pest status and crop condition. When potential problems are found, all applicable cultural, biological, and chemical options are carefully evaluated before a suitable control measure is chosen.

In part, the development of integrated pest management (IPM) is a response to the failure of many chemical pesticides to provide long-term solutions to pest problems. While some pesticides have dramatic effects when first applied, many pests develop resistance to the chemical over time and often re-emerge to plague an industry. It can become a vicious circle – the farmer increases the rate of pesticide application, producing increasingly resistant 'super-bugs'. Large quantities of the poisons enter the soils and waterways of the region, with sometimes unforeseen and devastating effects on the environment and human health. Some definitions of IPM are given below:

"Integrated pest management, or IPM is a systematic approach to crop protection that uses increased information and improved decision-making paradigms to reduce purchased inputs and improve economic, social, and environmental conditions on the farm and in society. Moreover, the concept emphasizes the integration of pest suppression technologies that include biological, chemical, legal, and cultural controls".

"Integrated pest management (IPM) is a pest management strategy that focuses on long-term prevention or suppression of pest problems with minimum impact on human health, the environment, and non-target organisms". "Preferred pest management techniques include encouraging naturally occurring biological control, using alternate plant species or varieties that resist pests, selecting pesticides with lower toxicity to humans or nontarget organisms; adoption of cultivating pruning, fertilizing, or irrigation practices that reduce pest problems; or changing the habitat to make it incompatible with pest development. Broad spectrum pesticides are used as a last resort when careful monitoring indicates they are needed according to pre-established guidelines."

"Integrated pest management is a sustainable approach to managing pests by combining biological, physical, and chemical tools in a way that minimizes economic, health, and environmental risks".

IPM benefits can be realized if the following steps are taken, in this order:

- (i) identify problems correctly
- (ii) determine the extent of the problem by sampling
- (iii) critically assess the importance of the problem
- (iv) evaluate and select appropriate management alternatives
- (v) implement selected management actions in a timely manner
- (vi) evaluate the effectiveness of control actions.

(a)Key Components of Integrated Pest Management:

Knowledge: Understanding the biology and ecology of the pest, and the crop (or livestock) is essential. Information about interactions within agricultural ecosystems is also important. IPM draws on the fundamental knowledge of plant and insect biology accumulated by biologists.

Monitoring: Farmers can use relatively simple techniques to keep track of what pests are where. This information, combined with knowledge of pest life cycles, can enable farmers to implement control measures at the most effective times. Monitoring on a broader scale can also be used to predict pest outbreaks and forewarn farmers to take action.

Economic threshold: This takes into account the revenue losses resulting from pest damage and the costs of treatment to prevent the damage. Below the economic threshold, the presence of the pest is tolerated. Only when pest numbers increase above the threshold does the farmer take action.

Adaptability: Farmers must keep informed about what is happening in their fields so that they can adapt their strategies to changing circumstances. Research scientists, too, must aim to keep at least one step ahead of the pest, which is also undoubtedly changing and adapting over time.

(b) Control Techniques in IPM: A wide range of pest control techniques are available to farmers. Some of them are as old as agriculture itself – rotating a crop, for example, to avoid a build-up of host-specific pests. Some are new – in recent years, genetic engineering has opened up many possibilities in pest control that were unavailable to agriculturists even a decade ago. The simple philosophy is that the control will be more effective, and resistance will be less likely to build up, when a range of measures are deployed against a pest. Wherever possible, different pest control techniques should work together rather than against each other. In some cases, this can lead to synergy – where the combined effect of different techniques is greater than would be expected from simply adding the individual effects together. Integrated pest management involves the integrated use of four basic control techniques (physical control, biological control, Genetic modification and of course, chemical control) as discussed below:

(i) Physical Control: Physical controls are those that can be carried out by the farmer to alter environmental factors in a way that reduces pest populations. A simple and common example of this is *crop rotation*, which is the practice of planting different crops each year in a given field. This interrupts the normal life cycle of some pests by changing their environment to one in which their favourite host plant does not feature. It is a strategy that has been used successfully for years by farmers. Another physical control method sometimes called 'mating disruption' involves the use of *sex pheromones*. These chemicals are produced by female insects to attract males for mating. For many insects, scientists have been able to analyze the chemistry of the sex pheromones and reproduce them synthetically in the lab. Quantities of the chemical placed around an orchard can disrupt mating – male insects become confused and are less likely to find a mate.

(ii) Biological control: The principle behind biological pest control is that a given pest has enemies – predators, parasites or pathogens. By introducing or encouraging such enemies, the population of pest organisms should decline. It is not a new concept. The ancient Chinese encouraged ants in citrus orchards because they attacked many citrus pests.

There are three general approaches to biological pest control. The first of these is *importation of a biological agent*. For example, the Mexican prickly pear once covered 250,000 square kilometres, mostly in Queensland (Australia), greatly reducing the land's carrying capacity for sheep and cattle. It was brought under control very effectively by the introduction of an Argentinean moth, *Cactoblastis cactorum*, the larvae of which eat the leaves of the offending plant. But there are dangers with this approach. Nowadays biologists are required to carry out extensive research before a control organism is released because it is important to find out whether it will attack species other than the pest species. The second approach to biological control is *augmentation*, which is the manipulation of existing natural enemies to increase their effectiveness. This can be achieved by mass production and periodic release of natural enemies of the pest, and by genetic enhancement of the enemies to increase their effectiveness at control. The third approach is conservation. This involves identifying and modifying factors that may limit the effectiveness of the natural enemy. In some situations, this may include reducing the application of pesticides, since such pesticides may kill predators at the same time as killing the pests. Sometimes part of a crop area is left untreated so that natural enemies will survive and recolonise the treated areas. Lady bird beetle, an important biocontrol agent, has been employed to control many pests (Figure 3).



Fig. 3: Lady Bird Beetle

(iii) Genetic Modification: Crop plants can be bred to be resistant to pests. Farmers have been doing this for centuries, selecting the seeds of those plants least affected by a pest for use in the next year's crop. This preferential selection is a form of genetic modification. With advances in biotechnology and molecular biology, it is becoming increasingly easy to transfer resistance genes into a plant – this is called gene transformation or genetic engineering. An example of genetic engineering is the insecticide-producing Bt gene in cotton. Scientists took the gene from a bacterium and inserted it into a plant, making the plant resistant to insect attack. Similarly, potato plants have been genetically modified to increase their resistance to potato leaf roll virus.

Another technique is the genetic modification of the pest itself. The idea is to engineer a disadvantageous trait in a pest and then release modified individuals into the outside world. The sterile insect release method is an example of this approach. The genetic engineering of organisms is controversial. Some people argue that toxins produced as a result of gene transfer may have harmful effects on beneficial organisms or on human health, while others suggest that the transferred gene might 'escape' into wild, related species of the modified organism, with possible ecological implications.

(iv) Chemical Control: The use of chemical pesticides often forms part of an integrated pest management strategy. The key is to use pesticides in a way that complements rather than hinders other elements in the strategy and which also limits negative environmental effects. It is important to understand the life cycle of a pest so that the pesticide can be applied when the pest is at its most vulnerable stage – the aim is to achieve maximum effect at minimum levels of pesticide.

(c) Examples of Successful IPM in India: Several organizations, including pesticide companies, have been actively involved in developing IPM techniques for adoption by farmers. Consequently, comprehensive IPM programs are developed for rice, cotton, sugarcane, pulses, oilseeds and vegetables. Some are discussed below:

(i) Sugarcane: Two notable examples of successful biological control in India are control of the sugarcane top borer, *Scirpophaga excerptalia*, with an indigenous larval parasite, *Isotema javensis*, and the control of sugarcane pyrilla, *Pyrilla perpusella*, with *Epiricania melanoleuca*. Inundative releases of *Trichogramma chilonis* and *T. japonicum* have been found to control borers effectively. The technology for mass-production of *Trichogramma* spp. and their field release is also available at National Centre for Integrated Pest Management (NCIPM), New Delhi.

(ii) Cotton: The IPM technology for rain-fed cotton was first formulated by NCIPM, New Delhi and tested in collaboration with cotton research station Nanded of Marathwada Agricultural University, Parbhani. Initially three modules, namely bio-intensive, biocontrol + intercrop, biocontrol + insecticide were evaluated in comparison to farmers' practices over 10 ha during 1997/98. The most promising module, namely bio-intensive, was taken up for large-scale validation and promotion in 200 ha during 1998/99 and was continued for 4 years. The main IPM interventions of this module were seed treatment with imidacloprid, scouting, placement of pheromone traps for monitoring, two releases of the egg parasitoid *Trichogramma chilonis*, one spray of HaNPV and two or three sprays of Neem Seed Kernel Extract (NSKE). The IPM module resulted in substantial reduction of pesticide use and conservation of natural fauna.

(iii) Basmati Rice: NCIPM, New Delhi initiated an IPM program in basmati rice in 1994 with a few acres of land area during *kharif* 2001. Later an entire village (Shikohpur) was taken for IPM validation in basmati rice, with a total of 400 acres of land under Pusa Basmati-1. Some improved crop management practices helped in improving the plant vigour and stand, such as planting of two or three seedlings per hill, planting of 'Dhaincha' (*Sesbania* sp.) for green manure before transplanting of rice and judicious use of fertilizer with addition of potash at 40 kg/ha. Regular pest surveillance and monitoring along with natural enemies of insect pests helped in reducing the IPM interventions to a bare minimum, which included seed treatment with carbendazim at 2 g/kg of seed, and one release of parasitoids *Trichogramma japonicum* when the incidence of leaf folder was found to be on the increase. Pesticide interventions included the use of carbendazim against sheath blight in a few infected patches (total area less than 10 acres) and streptomycin against bacterial leaf blight in some fields, not exceeding an area of 5 acres in total. Spraying of monocrotophos was done in a few fields (in about 2 acres) against gundhi bug and pollen beetle *Chiloloba* sp. Thus, from an average of five or six pesticide applications during earlier years, the farmers have come down to less than one spray.

(iv) Rapeseed-Mustard: The IPM program on rapeseed-mustard was initiated by NCIPM, New Delhi in 1995. A study with three treatments was undertaken: (i) IPM; (ii) chemical control measures; and (iii) farmers' usual practices (FP). The major components of IPM treatments included: timely sowing of the crop (15-25 October), seed treatment with *Trichoderma viride* at 2 g/kg seed, judicious use of fertilizers, mechanical removal of aphid infested twigs at the initial stage of attack etc. This module was validated in village Bhora Khurd district Gurgaon, Haryana during 1995 to 2001 on large area of 100 acres. Due to timely sowing, i.e. 15-25 October, the crop completely escaped from the incidence of mustard aphid (*Lipaphis erysimin*), white rust (*Albugo candida*) and *Alternaria* leaf spot during all the years of trial. The farmers were educated about the concept of IPM, identification of crop insect pests, benefits of regular monitoring of insect pests through 'FFS of IPM' regularly.

(v) Chickpea: An eco-friendly IPM program in chickpea at four locations in three states was initiated by NCIPM, New Delhi. The main IPM components were seed treatment with *Trichoderma* + Vitavax (carboxin), chloropyrifos and *Rhizobium*, pheromone traps for pest monitoring and foliar spray of HNPV and NSKE and one spray of endosulfan (need based). In farmers' practice (FP) around three foliar sprays of insecticides were applied as mixture and or alone (parathion methyl, dichlorvos and monocrotophos). The average yield obtained in IPM trials was 2700 kg/ha as against 1500 kg/ha in FP trials.

(d)Major Constraints to IPM in India: A major limitation is the lack of trained personnel. Many farmers are not trained adequately in augmentative biological control, leading to misunderstanding of its potential efficacy. Logistical problems such as improper timing and delays in shipment can alter the effectiveness of natural enemies. Farmers often believe that natural enemies do not work well, and that low pest populations will cause losses. The use of biopesticides is limited due to moderate toxicity, slow action, host specificity and photo-instability as well as a higher cost. Many farmers are not yet aware of the proper usage and available suppliers of biocontrol agents and biopesticides. A number of botanicals such as karanj, mahua, nuxvomica, custard apple, ipomoea, garlic and tobacco have been found to be effective against insect pests and diseases, however in absence of detailed scientific data, except for neem, most of them are localized to rural pockets. Botanicals, particularly neem, have not found much favour with farmers. The necessity for repeated applications, low toxicity and persistence, cumbersome procedures of collection and extraction coupled with low yields have discouraged wide use of neem. IPM adoption is influenced by the cost versus efficacy of products, need for sophisticated information for decision making, ability to integrate new products and techniques into existing farm management practices and managerial skills. Strategies that are being modified to achieve the goal of wider adoption of IPM.

4. Integrated Weed Management (IWM): A farming system that utilizes an array of inter-dependent cultural, biological and herbicidal weed control practices is generally referred as Integrated Weed Management (IWM). It is essential that IWM involves an array of tools including the rotation of available herbicide groups, ensuring that weeds are exposed to a diverse range of control mechanisms. The principal aim of IWM is to reduce selection for resistance to any single control agent and to delay or prevent the development of herbicide resistant weeds. The different components of IWM are discussed below:

(i) Preventative Strategies: Prevention is the most important but often least used control strategy. Wind, water, wild animals, livestock and man are the major agents of weed dispersal. When weeds are spread by natural agents, control is very difficult or impossible. When man is the weed dispersal agent, carelessness or a lack of understanding of his actions is responsible. Following preventive strategies could be followed to stop the entry of weeds into new area:

- sow certified crop seeds. In the long run, cheap seed is usually the most expensive. Certified seed has a lower allowable tolerance for noxious weed seeds
- clean machinery and vehicles. Wash farm machinery before transport to clean weeds and mud which contains weed seeds. Tarp grain loads to prevent seed spread
- cut weed infested crops prior to weed seed production
- clean hair and feet of animals prior to moving
- control weeds in feed and bedding grounds. Many weed seeds pass through the animal's digestive tract intact and viable
- use only well rotted manure. Storage should generally be four to five months.

(ii) Physical Strategies

Tillage: Soil is the principal factor of the environment that the farmer manipulates in crop production. Soil tillage enables the farmer to attack many weed survival mechanisms. For annual weeds, the tillage objective is to prevent seed production and deplete current seed reserves in the

soil. This is accomplished by encouraging weed seeds to germinate, then subsequently killing them. With perennials, destruction of the underground parts is sought, as well as the prevention of seed production and reduction of seed reserves. Tillage kills weeds by:

- burial of the entire plant. If complete burial is not accomplished and a small portion of the plant is exposed, life may continue. Burial is usually only effective with seedlings
- depleting food reserves. This is accomplished by repeatedly removing top growth whenever it reaches sufficient size. Food manufacture can be halted by cutting off the plant tops or burning them. Tillage that breaks the underground parts into pieces is also very effective. This creates more growing points to use up food, and hastens food depletion
- exposure of underground parts to frost. The roots of most plants are killed when left on or near the soil surface during freezing temperatures
- exposure of root systems to drying. If many roots remain under moist soil, growth will continue, therefore tillage must be thorough, with the plants fully exposed on the soil surface
- encouraging rotting of underground parts. Physical injury to underground parts due to tillage enables the entry of decay causing bacteria

Deep tillage buries weed seeds and temporarily minimizes weed problems, but subsequent tillage will bring these seeds to the surface again. Seeds in the soil can germinate many years after burial - sometimes for up to 40 years or more.

Hand Weeding: Annual and biennial weeds and non-creeping perennials can be destroyed by simply pulling them out. This is best done when the soil is moist and before seed is produced. This is only practical of course for small patches or individual plants.

Mowing: When weeds are too numerous to hand pull, too large to effectively destroy by cultivation, or in an area where cultivation is impractical or impossible, they can be destroyed by mowing. This should be done before they produce seed and as close to the ground as possible. Perennial weeds usually require several cuttings before the food reserves in the roots are exhausted. If only a single cutting can be made, the best time is just prior to blooming because: the reserve food supply in the roots is at its lowest level, and viable seed is often produced just after blooming.

Grazing: The repeated removal of weed top growth by grazing animals, like close mowing, prevents seed formation and gradually weakens underground parts. Horses, sheep, goats, and cattle are effective in destroying many weeds, if they are properly managed. By rotating the pastures, desirable forage is encouraged during its rest period and results in healthier competitive pasture plants. Rotation also permits herbicide treatment with a safety margin, enabling the breakdown of the chemical before returning the pasture to grazing.

Burning: In situations when seed production has already occurred, some of the seeds can be destroyed by burning. The effectiveness of burning depends on the duration and intensity of heat produced, plus the maturity and location of the seeds. Mature, dry seeds are more heat resistant than green seeds, which have high moisture content. Although intense heat will destroy most seeds remaining in plant heads, only a relatively small number of seeds on or below the soil surface can be destroyed by burning surface trash. Burning weeds over an extended area destroys

valuable surface trash that would normally be returned to the soil through decay or cultivation. In most farming operations, the most appropriate use of burning would be to selectively burn patches of weeds that have headed out.

Mulching: The principle of mulching is to exclude light from the tops of the weeds until the reserve food supply in the roots is depleted and the weeds starve. Mulches include clean straw, hay or manure, tar paper, sawdust and black plastic. Black plastic is very effective. When the vegetation under the mulch has been destroyed, the resultant bare patch must be reseeded with competitive vegetation to prevent new weed introductions.

(iii) Cultural strategies: Cultural control uses plant competition or cropping practices to suppress weeds, either through use of smother or competitive crops and crop rotation.

Crop Rotations: Certain groups of weeds are almost always associated with specific crop rotations because:

- they are able to compete well with that crop
- they are not destroyed by the herbicides and cultivations that normally accompany production of the crop

Continuous cropping of same crop results in an increase in weed populations, chiefly annuals. Perennial forage crop plantings or permanent pastures favour development of perennial weeds. Repeated plantings of the same crop favour the development of insects and diseases which result in weak or patchy stands which are easily invaded by weeds. Annual weeds in cereals can be reduced by rotating with legumes or following intercropping with legumes.

Plant Competition: The use of plant competition is one of the cheapest and most useful general weed control practices available to all farmers. Competition uses one of nature's oldest laws - survival of the fittest. Weeds are strong competitors by nature. If not, they would fail nature's survival tests. Certain weeds that can best compete under a certain set of circumstances always tend to dominate. Weeds compete with crop plants for light, soil moisture, soil nutrients, carbon dioxide, and space. Usually, early weed competition reduces crop yield far greater than late season weed growth. It naturally follows then, that early weed control is exceptionally important. Late season weed growth may not seriously reduce yields, but it can make harvesting difficult, lower crop quality, and add to the reservoir of weed seeds in the soil. Therefore, optimum plant population needs to be adjusted to control the weeds. The most that should be expected is suppression of weed growth and a measure of practical control through competition. Competition is a good secondary tool and is most effective when used in combination with other control strategies.

Crop Establishment: As a general rule, the first plants to germinate and emerge in an area tend to exclude all others. Therefore, it is critical when considering plant competition as a weed management tool to establish a vigorous dense crop. Important factors that affect germination and emergence include the viability of the crop seed (percent germination), soil temperature, availability of moisture, and physical resistance to seeding emergence by the soil. These factors are influenced by the soil type, physical condition of the soil, depth of planting, the firmness of soil around the seed, the degree of soil compaction above the seed, and the formation of surface crusts after planting. The final stand will also be influenced by post-emergent stress due to

weeds, diseases, insects and adverse weather conditions. Crop germination, if sowing/planting has been correctly done, is generally rapid and predictable. If pre-seeding weed growth has been killed, at least a temporary advantage has been gained for the crop. This initial advantage can be lost however, if effective post-seeding herbicide application or tillage is not undertaken to control late emerging weeds.

Prepare Good Seedbed - Stale Seedbed Technique: A good seedbed is prepared, but no seeds are planted. After a good growth of weeds has emerged, they are killed using a non-selective herbicide with no residual effect in the soil. The crop is then planted with as little disturbance of the soil as possible to avoid bringing fresh weed seeds to the surface. This technique controls the all important first flush of weeds.

Rate of Seeding: Heavier seeding rates can be used to reduce weed competition in areas where sufficient moisture is available. This applies to seeding completed at the regular time, as well as in a delayed seeding program. The recommended heavy seeding rate varies from 25 to 100 percent more seed, depending on the crop and the location. However, it should be remembered that heavy seeding rates should be used together with other cultural and chemical control measures to be most effective.

Crop Variety: It is important to choose a variety of crop plant that is well adapted to local conditions of soil, water, climate and disease resistance.

Fertilization: The fertility of the soil affects both the vigour of crop plants and the vigour of weeds. Many weeds can utilize fertilizers as well as or better than crop plants. Nevertheless, if most of the weeds are suppressed or killed by tillage or herbicides, the extra vigour given to the crop by fertilizers will make them better competitors. Placement of the fertilizer in the crop rows has an advantage over broadcast fertilization because most of the fertilizer is directly available to the crop.

Smother Crops: A smother crop is defined as a thick stand of rapidly growing crop that competes with weeds to such an extent that their top growth is drastically suppressed and their roots are severely weakened. Extensive root system of smother crops enables them to compete with most weeds for water, and their dense top growth smothers new weed growth. The principal value of smother crops in weed control is that they severely weaken the underground parts so that weeds are readily killed by the cultivation that follows.

Soil - Water Relationships: Water relations, particularly the quantity of rainfall and its distribution, are critical to growth. Soil type, texture and the height of the water table are also important. Most land cropped with cereals and vegetables is sufficiently drained that any improvement of the overall drainage would have little effect on weeds.

Soil Reaction: Certain weeds tend to be associated with alkaline and acid soils. For example, wild barley and arrow grass are more prevalent on alkaline soils. Wild oats do better on acid soils than most cereals. Amending soil reaction is suggested where indicator weed species prevail.

(iv) Biological Strategies: Biological control refers to the use of natural agents such as insects, nematodes, fungi, viruses or fish for the control of weeds. In some instances, grazing animals can be used to harvest and stress noxious weeds. There have been a number of successes using bio-control and this method is receiving increased attention in the world. The objective in bio-control is never eradication; it is reduction of a weed's density to non-economic levels. Bio-control

begins by first looking at the natural enemies of a particular weed in its native country. When a suitable control agent has been found, it is screened to ensure that the agent is specific only to the target weed and not to crops and other desirable plants as well. When screening is complete, the insects are increased and permission to release is received from the competent authorities.

Bio-control is a self-regulating type of weed control. That is, as the weed host increases so does the insect population. As the weed population decreases due to the insect, the insect population also decreases. A balance is hopefully attained where the weed and insect populations are held at a low level. Bio-control is designed for the most part for non-cultivated lands where biennial or perennial weeds are troublesome. Cultivated lands are not usually suitable as the weed food source for the biotic agent is removed periodically. Biological weed control is the ultimate in controlling undesirable vegetation as it uses natural forces in a way which will least upset the environment. Much experimentation and screening has yet to be done, however, before this method can be used to the exclusion of alternate control measures for many of our noxious weedy plants.

(v) Chemical strategies: Man began to experiment with chemicals to control weeds in the 19th Century but it was the phenomenal success of 2,4-D, introduced commercially in 1940s, that launched the present era of herbicides. It is important to understand a few basics of herbicides and their use so that they might be used effectively as a component of an integrated weed management program.

Steps to Reduce Herbicide Use

- use herbicides only when weeds are in the susceptible stage
- use herbicides only when weather and soil conditions are appropriate for effective control
- use wipe-on technology where appropriate for weeds growing above the crop
- use band treatments over the row and cultivation between rows
- properly maintain application equipment and accurately calibrate
- read the herbicide label before use

5. Integrated Nutrient Management (INM): Integrated nutrient management (INM) is an approach to soil fertility management that combines organic and mineral methods of soil fertilization with physical and biological measures for soil and water conservation. INM adopts a holistic view of plant nutrient management by considering the totality of the farm resources that can be used as plant nutrients. It is based on three fundamental principles:

- maximize the use of organic material
- ensure access to inorganic fertilizer and improve the efficiency of its use
- minimize losses of plant nutrients

Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output and incomes, especially for low-income groups, without depleting the natural resource base. In this context, INM maintains soils as storehouses of plant nutrients that are essential for vegetative growth. INM's goal is to integrate the use of all natural and man-made sources of plant nutrients, so that crop productivity increases in an efficient and environmentally benign manner, without sacrificing soil productivity of future generations. INM

relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers.

Balanced application of appropriate fertilizers is a major component of INM. Fertilizers need to be applied at the level required for optimal crop growth based on crop requirements and agroclimatic considerations. At the same time, negative externalities should be minimized. Over application of fertilizers, while inexpensive for some farmers in developed countries, induces neither substantially greater crop nutrient uptake nor significantly higher yields. Rather, excessive nutrient applications are economically wasteful and can damage the environment. Under application, on the other hand, can retard crop growth and lower yields in the short term, and in the long term jeopardize sustainability through soil mining and erosion. The wrong kind of nutrient application can be wasteful as well. Balanced fertilization should also include secondary nutrients and micronutrients, both of which are often most readily available from organic fertilizers such as animal and green manures.

Nutrient conservation in the soil is another critical component of INM. Soil conservation technologies prevent the physical loss of soil and nutrients through leaching and erosion and fall into three general categories. First, practices such as terracing, alley cropping, and low-till farming alter the local physical environment of the field and thereby prevent soil and nutrients from being carried away. Second, mulch application, cover crops, intercropping, and biological nitrogen fixation act as physical barriers to wind and water erosion and help to improve soil characteristics and structure. Lastly, organic manures such as animal and green manures also aid soil conservation by improving soil structure and replenishing secondary nutrients and micronutrients. Improved application and targeting of inorganic and organic fertilizer not only conserves nutrients in the soil, but makes nutrient uptake more efficient.

Rice Integrated Crop Management (RICM): An Example of ICM

Rice growing is a production system involving a wide range of component factors. Rice farmers carry out a large number of management activities, including: development and maintenance of the rice field infrastructure (field levels and grade and the system of bunds with supply channels and drains); selection of variety and seed source; determination of the sowing and cropping calendar; land preparation practices; plant establishment techniques; protection from weeds, insects, diseases and other pests; nutrition supply to meet growth needs; management of water supply and depth control; and harvesting and grain storage. All these activities, singularly and collectively, affect the production of biomass in all phases of crop development, which ultimately determines the parameters of plant growth, yield components and yield. Crop development phases include germination, seedlings, vegetative development and reproduction from panicle initiation through flowering to grain ripening and maturity. Rice crop management programmes involve the formulation and transfer of technological recommendations for rice production throughout the entire growing season and often also include rotation factors.

The system to formulate technological recommendations for rice crop management has evolved slowly over the last 20 to 30 years. It has developed concurrently with changes in extension strategies and methodology. Technological recommendations for rice crop management have evolved from a single problem or component focus to a broader integrated system, with emphasis on the interaction and relationships between the system components. The extension

approach is evolving from a top-down, directional and authoritarian “*this is what you must do*” to a more participatory, facilitative and knowledge-processing approach involving farmers, researchers, extension officers and related stakeholders in the development of recommendations and technology sharing.

The concept of integration was, therefore, introduced in the 1980s in the formulation of technological recommendations for rice crop management, with the development of Integrated Pest Management (IPM), Integrated Weed Management (IWM) and Integrated Nutrient Management (INM) programmes. These approaches attempted to broaden the understanding of the range of factors affecting pest or weed growth and development or fertilizer response of rice, and to involve these factors in the farmer’s decision-making process. While these programmes created improvements and benefits, the technology focus was still relatively narrow, generally involving only specific areas of crop management: insect management, weed management or nutrient provision. However, the concept of integrated management was beginning to develop and influence attitudes towards crop management.

Over the last 10 to 15 years, a broader system of rice crop management - Rice Integrated Crop Management (RICM) - has been developed for irrigated rice production in many areas, covering diverse climates and socio-economic environments, such as Burkina Faso (Nguyen *et al.*, 1994), Australia (Lacy *et al.*, 1993; Clampett *et al.*, 2001), Egypt (Badawi, 2001), Korea (Moon, 2001), Senegal (Nguyen, 2002) and the whole Sahel zone of West Africa (Wopereis *et al.*, 2001). The RICM system seeks to develop a management approach at farm level that manages the growing of rice crops as a total production system, taking into account all factors affecting yield and quality. It takes into account the interactions and interdependencies among management technologies. It also provides a framework that helps farmers to evaluate their management skills and to recognize their strengths and weaknesses in order that the management of subsequent rice crops may be improved. Among the RICM systems, the Australian *Ricecheck* system, which will be discussed in detail, is outstanding in terms of its success in raising productivity and its innovations.

The Australian *Ricecheck* Programme

This successful and innovative programme is represented diagrammatically in Figure 4. It has three broad-linked components: the *Ricecheck* system, discussion groups and the specific technology programme.

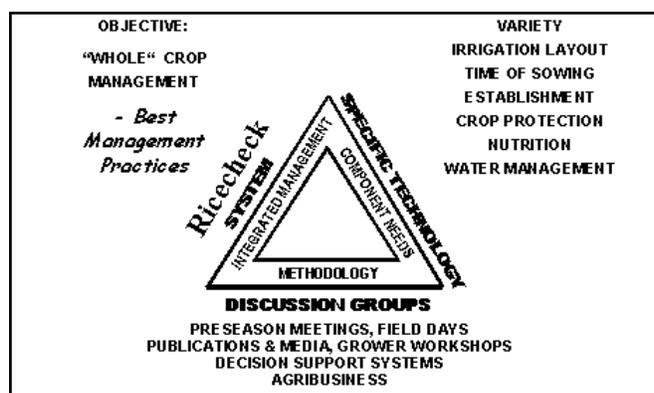


Fig. 4: Key elements of the Australian *Ricecheck* Program

(i)The *Ricecheck* System: Results obtained in Australia also showed that not only rice yield, but also the efficiency of nitrogen fertilizer application in rice production were obtained with the application of the *Ricecheck* system. The increase in nitrogen efficiency due to the application of the *Ricecheck* system reduced not only production costs but also the negative effects of nitrogen losses on the environment. The *Ricecheck* system provides recommendations that are the “best management practices” for rice growing, based on knowledge from research, latest known technologies and farming experiences. It works on the principle that to obtain optimal yield, the management of production inputs must achieve optimum output levels at every crop growth phase or in every management area. It provides both input and output recommendations. Input recommendations are the recommended technologies and materials for use in managing rice crops at different growth phases. Output recommendations are the optimal results to be aimed at by crop management in the various growth phases. Relationships between input practices, growth and management outputs, and yield, grain quality and environmental outcomes are summarized in Table 2. For example, a seed rate (e.g. 120 kg/ha of good seed) is the recommended input for achieving a desired plant stand of rice at 20 days after seeding (e.g. 150 plants/m²) - an output recommendation. The output recommendation (e.g. 150 plants/m²) serves as a criterion or benchmark for the evaluation of farmers’ success or failure in managing crop establishment.

Table 2: Examples of relationships between input practices, growth and management outputs, and yield, grain quality and environmental outcomes

Inputs - the practices	Outputs - the results	Outcome - the final impacts
Cultivation, vegetation control, levelling, seed rates, sowing techniques, water depths, time of sowing, pest control	Plants/m ² 100% uniform plant coverage	Yield Grain quality
Cultivation, nitrogen rates, timing, application, water management, pest and weed control, time of sowing	Nitrogen uptake kg/ha	Yield Grain quality
Field irrigation layout, banks (bunds), channels, water supply rates and depth control, drainage	Specific water depths growth stage	Yield
Cultivation, sowing time, establishment, plant stand and uniformity, pre-harvest, draining, nitrogen supply, harvest time	Grain moisture harvest	Grain quality
Field irrigation layout, land preparation, time of sowing, establishment, field drainage, water management, pesticide use and timing,	Pesticide residue levels in field drainage water	Environmental impact

In the formulation of technological recommendations, the *Ricecheck* system takes into account the fact that each single practice affects a range of management practices and outputs, thus reinforcing the importance of the need for integrated management. For example, land preparation affects a wide range of outputs, such as seedling number, weed population, nitrogen uptake and pest population. Seedling number (an output of land preparation) in turn affects the technological recommendations for weed management and nitrogen fertilizer application. The outputs at different phases of crop growth, when combined and allowed to interact together, result in yield, grain quality, environmental impacts and economic return.

While numerous factors affect yield and other outcomes, attention is focused on key factors. These recommendations are called “key checks”. The key checks for yield optimization cover eight “management areas” (see text box 1). A management area may include one or more key checks, including benchmarks and/or objective targets, as well as minor targets.

Text Box 1. The Australian RICM or Rice check

The Rice check has only 8 key checks, which are the following:

1. Key Check 1: Develop a good field layout with a land, which forms even grade between well constructed banks of a minimum height of 40 cm (measured at the lowest point).
2. Key Check 2: Use the recommended sowing dates.
3. Key Check 3: Obtain good or economic weed control.
4. Key Check 4: Establish a seedling population of 150-300 plants per square metre.
5. Key Check 5: Achieve an optimum crop growth level at panicle initiation of 500 - 1100 shoots per square metre and NIR (near infrared) tissue nitrogen content of 1.2% - 2.2% depending on variety.
6. Key Check 6: Topdress nitrogen based on shoot counts and NIR tissue analysis using NIR tissue test.
7. Key Check 7: Achieve an early pollen microspore water depth of 20-25 cm on the high side of each bay for Amaroo, Bogan, Jarrah, YRL 34 and Doongara; and 25 cm for Pelde, YRL 9 and Goolarah.
8. Key Check 8: Harvest as soon as possible, after physiological maturity, when the grain first reaches 22% moisture.

Understanding the concept of Rice Integrated Crop Management: It is important for those who develop the RICM system to understand and be committed to the approach as a management and extension tool for yield improvement, or at least to be prepared to objectively evaluate the concept. A number of factors are important:

- To achieve a certain yield level, a rice crop must attain a certain level of growth and development.
- Management - i.e. the integration and application of a technology - should promote optimal development in all growth stages.
- The management factors affecting crop development are interrelated and interdependent, and their combined effects in varying degrees have an impact on all growth and yield, grain quality and environmental outcomes.
- The specifications for RICM vary depending upon local agro-ecological conditions.
- RICM should differentiate between inputs (the practices of what needs to be done) and outputs (what has to be achieved) in developing the outcomes required (yield and quality and environmental impacts).
- A benchmarking or checking process must be developed to assist farmers in the evaluation of the achievements of their management and in the improvement of future crops.

Formulation of the RICM system: The input and output recommendations should be based on the best management practice (BMP) for the particular agro-ecological conditions and local level of management.

“Best Management Practices can be defined as those practices best able to achieve the results required given the available technology and knowledge, the practical experience on commercial farms, and the resources, understanding and capabilities of the rice farmers. They should reflect what is perceived as achievable and desirable. They are not necessarily those practices that the most recent research results would support.”

BMPs can be developed from the practices of the best farmers and from the knowledge and experience of research and extension officers. The key management areas may vary, depending upon the local agro-ecological conditions and the level of crop management in the local area. It is also important to consider recommendations in the context of inputs (what you want the farmer to do) and outputs (how the practices aim to achieve optimum growth and yield, quality and environmental conservation). In the development of the RICM system, it should be remembered that farmers do not start at the same level of management: it is important to start where farmers are and not where you want them to be.

Therefore, the concept of Rice Integrated Crop Management (RICM), as discussed above, can be extended to develop ICM package for other field crops in India.

Good Agricultural Practices for Selected Agricultural Components

Broadly defined, good agricultural practices (GAP) applies available knowledge to addressing environmental, economic and social sustainability for on-farm production and post-production processes resulting in safe and healthy food and non-food agricultural products. Many farmers in developed and developing countries already apply GAP through sustainable agricultural methods such as integrated pest management, integrated nutrient management and conservation agriculture. These methods are applied in a range of farming systems and scales of production units, including as a contribution to food security, facilitated by supportive government policies and programmes. Following GAPs have been suggested by Committee on Agriculture (Development of a Framework for Good Agricultural Practices, Seventeenth Session, FAO, Rome, 31 March-4 April 2003):

Soil

i) The physical and chemical properties and functions, organic matter and biological activity of the soil are fundamental to sustaining agricultural production and determine, in their complexity, soil fertility and productivity. Appropriate soil management aims to maintain and improve soil productivity by improving the availability and plant uptake of water and nutrients through enhancing soil biological activity, replenishing soil organic matter and soil moisture, and minimizing losses of soil, nutrients, and agrochemicals through erosion, runoff and leaching into surface or ground water. Though soil management is generally undertaken at field/farm level, it affects the surrounding area or catchment due to off-site impacts on runoff, sediments, nutrients movement, and mobility of livestock and associated species including predators, pests and biocontrol agents.

ii) Good practices related to soil include maintaining or improving soil organic matter through the use of soil carbon-build up by appropriate crop rotations, manure application, pasture management and other land use practices, rational mechanical and/or conservation tillage practices; maintaining soil cover to provide a conducive habitat for soil biota, minimizing erosion losses by wind and/or water; and application of organic and mineral fertilizers and other agro-chemicals in amounts and timing and by methods appropriate to agronomic, environmental and human health requirements.

Water

iii) Agriculture carries a high responsibility for the management of water resources in quantitative and qualitative terms. Careful management of water resources and efficient use of water for rainfed crop and pasture production, for irrigation where applicable, and for livestock, are criteria for GAP. Efficient irrigation technologies and management will minimize waste and will avoid excessive leaching and salinization. Water tables should be managed to prevent excessive rise or fall.

iv) Good practices related to water will include those that maximize water infiltration and minimize unproductive efflux of surface waters from watersheds; manage ground and soil water by proper use, or avoidance of drainage where required; improve soil structure and increase soil organic matter content; apply production inputs, including waste or recycled products of organic, inorganic and synthetic nature by practices that avoid contamination of water resources; adopt techniques to monitor crop and soil water status, accurately schedule irrigation, and prevent soil salinization by adopting water-saving measures and re-cycling where possible; enhance the functioning of the water cycle by establishing permanent cover, or maintaining or restoring wetlands as needed; manage water tables to prevent excessive extraction or accumulation; and provide adequate, safe, clean watering points for livestock.

Crop and Fodder Production

v) Crop and fodder production involves the selection of annual and perennial crops, their cultivars and varieties, to meet local consumer and market needs according to their suitability to the site and their role within the crop rotation for the management of soil fertility, pests and diseases, and their response to available inputs. Perennial crops are used to provide long-term production options and opportunities for intercropping. Annual crops are grown in sequences, including those with pasture, to maximize the biological benefits of interactions between species and to maintain productivity. Harvesting of all crop and animal products removes their nutrient content from the site and must ultimately be replaced to maintain long-term productivity.

vi) Good practices related to crop and fodder production will include those that select cultivars and varieties on an understanding of their characteristics, including response to sowing or planting time, productivity, quality, market acceptability and nutritional value, disease and stress resistance, edaphic and climatic adaptability, and response to fertilizers and agrochemicals; devise crop sequences to optimize use of labour and equipment and maximize the biological benefits of weed control by competition, mechanical, biological and herbicide options, provision of non-host crops to minimize disease and, where appropriate, inclusion of legumes to provide a biological source of nitrogen; apply fertilizers, organic and inorganic, in a balanced fashion, with appropriate methods and equipment and at adequate intervals to replace nutrients extracted by harvest or lost during production; maximize the benefits to soil and nutrient stability by re-

cycling crop and other organic residues; integrate livestock into crop rotations and utilize the nutrient cycling provided by grazing or housed livestock to benefit the fertility of the entire farm; rotate livestock on pastures to allow for healthy re-growth of pasture; and adhere to safety regulations and observe established safety standards for the operation of equipment and machinery for crop and fodder production.

Crop Protection

vii) Maintenance of crop health is essential for successful farming for both yield and quality of produce. This requires long-term strategies to manage risks by the use of disease- and pest-resistant crops, crop and pasture rotations, disease breaks for susceptible crops, and the judicious use of agrochemicals to control weeds, pests, and diseases following the principles of Integrated Pest Management. Any measure for crop protection, but particularly those involving substances that are harmful for humans or the environment, must only be carried out with consideration for potential negative impacts and with full knowledge and appropriate equipment.

viii) Good practices related to crop protection will include those that use resistant cultivars and varieties, crop sequences, associations, and cultural practices that maximize biological prevention of pests and diseases; maintain regular and quantitative assessment of the balance status between pests and diseases and beneficial organisms of all crops; adopt organic control practices where and when applicable; apply pest and disease forecasting techniques where available; determine interventions following consideration of all possible methods and their short- and long-term effects on farm productivity and environmental implications in order to minimize the use of agrochemicals, in particular to promote integrated pest management (IPM); store and use agrochemicals according to legal requirements of registration for individual crops, rates, timings, and pre-harvest intervals; ensure that agrochemicals are only applied by specially trained and knowledgeable persons; ensure that equipment used for the handling and application of agrochemicals complies with established safety and maintenance standards; and maintain accurate records of agrochemical use.

Harvest and On-farm Processing and Storage

ix) Product quality also depends upon implementation of acceptable protocols for harvesting, storage, and where appropriate, processing of farm products. Harvesting must conform to regulations relating to pre-harvest intervals for agrochemicals and withholding periods for veterinary medicines. Food produce should be stored under appropriate conditions of temperature and humidity in space designed and reserved for that purpose. Operations involving animals, such as shearing and slaughter, must adhere to animal health and welfare standards.

x) Good practices related to harvest and on-farm processing and storage will include those that harvest food products following relevant pre-harvest intervals and withholding periods; provide for clean and safe handling for on-farm processing of products. For washing, use recommended detergents and clean water; store food products under hygienic and appropriate environmental conditions; pack food produce for transport from the farm in clean and appropriate containers; and use methods of pre-slaughter handling and slaughter that are humane and appropriate for each species, with attention to supervision, training of staff and proper maintenance of equipment.

Energy and Waste Management

xi) Energy and waste management are also components of sustainable production systems. Farms require fuel to drive machinery for cultural operations, for processing, and for transport. The objective is to perform operations in a timely fashion, reduce the drudgery of human labour, improve efficiency, diversify energy sources, and reduce energy use.

xii) Good practices related to energy and waste management will include those that establish input-output plans for farm energy, nutrients, and agrochemicals to ensure efficient use and safe disposal; adopt energy saving practices in building design, machinery size, maintenance, and use; investigate alternative energy sources to fossil fuels (wind, solar, biofuels) and adopt them where feasible; recycle organic wastes and inorganic materials, where possible; minimize non-usable wastes and dispose of them responsibly; store fertilizers and agrochemicals securely and in accordance with legislation; establish emergency action procedures to minimize the risk of pollution from accidents; and maintain accurate records of energy use, storage, and disposal.

Conclusion

After the observation of negative effects of the green revolution on natural resources, the call arose for new systems of management. The anthropologists and sociologists studied age-old practices again as they survived the test of time, and stated that these methods have something to offer due to their sustainability. However, the recently developed systems of integrated management require large-scale testing prior to adoption. The new crops and varieties need to be evaluated under the field conditions of the developing countries. Although emphasis is today on basic research, there is a growing need to popularize and facilitate research on agronomic aspects of these crops and systems. These will include studies ranging from land preparation through seeding and propagation and management up to harvesting. It is only under such conditions that the people who produce food for increasing populations, especially in the tropical developing countries, would adopt integrated management systems of agriculture, which to date have had very little emphasis and research backing. The future of success of crop production lies in the growth of crops with less environmental stress. Ecological models will help in the understanding of processes and indicate ways of developing suitable techniques. Thus emphasis needs to be placed on practical aspects of sophisticated techniques by crop scientists and agronomists, both in the developed and developing world.

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