

Integrated crop management technology

for resilient agri-food systems and environmental stewardship

Anamika Barman¹, Vijay Pooniya^{1*}, Anil K. Choudhary² and Arjun Singh¹

¹ICAR-Indian Agricultural Research Institute, New Delhi 110 012

²ICAR-Central Potato Research Institute, Shimla, Himachal Pradesh 170 001

Agriculture contributes ~16% to India's GDP and sustains nearly half of its population, making it central to food security and rural livelihoods. The Green Revolution enhanced self-reliance in foodgrains production and drove growth through scientific and policy interventions. However, conventional practices have degraded soil health, water resources, and biodiversity while reducing factor productivity and resource use efficiency. Challenges include groundwater decline, soil organic matter loss, pest and disease resurgence, pesticide residues, and herbicide resistance. Coupled with socio-economic shifts such as urbanization, labour migration, and changing diets, these issues necessitate climate-resilient, resource-efficient, and sustainable agricultural approaches.

Keywords: Environmental security, Food safety and quality, Integrated crop management, Resilient agri-food systems, Sustainable agriculture

ACCORDING to the FAO, Integrated Crop Management (ICM) has recently emerged as a comprehensive and more impactful strategy compared to managing soil, water, nutrients, crops, pests, diseases, and energy in isolation. ICM brings together the most appropriate agronomic practices needed to achieve higher productivity. These include methods of tillage and crop establishment, Integrated Nutrient Management (INM), Integrated Weed Management (IWM), Integrated Water Management (IWm), Integrated Disease Management (IDM), and Integrated Pest Management (IPM), among others. It also emphasizes the combined management of tillage and water resources in a coordinated manner. This approach is especially valuable for small and marginal farmers since it reduces reliance on costly external inputs and promotes better use of on-farm resources. By addressing not only the production aspects but also socio-economic and environmental dimensions, ICM provides a holistic pathway to sustainable agriculture. Its goal is to identify practices that are safe, efficient, and adaptable, ensuring both immediate productivity and long-term ecological and economic benefits. In above context, there is urgent need to have appropriate resource-management strategies in crop production. ICM is a pragmatic approach which includes IPM, soil, social and environmental management. Literary, ICM is composed of 3 words, namely integrated, crop and management:

- Integrated refers to a holistic, site-specific approach

that considers the entire production system as one unit.

- Crop signifies the inclusion of every component of crop husbandry and cultivation practices.
- Management encompasses the processes of planning, goal-setting, implementation, supervision, evaluation, and attaining the desired outcomes.

ICM brings together a range of farming practices such as crop rotation, tillage methods, selection of suitable varieties, and the careful use of fertilizers and pesticides in an environment-friendly way. More importantly, ICM represents a structured system of farming that requires careful planning, implementation, target setting, and regular monitoring. This approach merges advanced crop production technologies with fundamental principles of good agricultural practice, aiming to reduce wastage, improve energy efficiency, and lower pollution levels. It is not only a whole-farm approach but also a long-term strategy. ICM ensures that farm enterprises remain profitable while being environmentally responsible and resource-sensitive. The system focuses on sustainable crop production by protecting and enriching natural resources, while ensuring the supply of safe and quality food in an economically feasible way. Its foundation lies in understanding the interactions between biological processes, ecological systems, and land management practices. In essence, ICM emphasizes efficient food and



Major components of integrated crop management (ICM)(Source: Choudhary *et al.* 2020)

product supply, reduced dependence on non-renewable inputs, conservation of soil, water, and air quality, and the protection of biodiversity within agricultural landscapes. The approach is guided by five key principles, viz. Food security, Environmental security, Economic viability, Social acceptability, and Food safety and quality.

Therefore, ICM practices hold considerable potential for enhancing yield, improving productivity, and raising profitability, particularly for smallholder farmers. These practices are designed and fine-tuned in partnership with farmers so that they address local requirements and constraints effectively. As new research insights and technologies emerge, ICM options must also be revised and refined to remain relevant. When such technologies are developed through active participation of farmers, the chances of their acceptance and long-term adoption increase substantially.

ICM: An innovative approach for resilient agri-food systems

ICM offers an alternative framework for crop production that emphasizes the conservation and enhancement of natural resources while ensuring the supply of high-quality food in a cost-effective and sustainable manner. It takes into account integrated tillage and water management strategies in a holistic way. ICM merges time-tested traditional practices with relevant modern technologies to strike a balance between profitable crop production and environmentally sound farming. As a whole-farm strategy, ICM provides the foundation for efficient, productive, and profitable agriculture that is both economically feasible and ecologically responsible. In practice, ICM reflects the

principles of sound agronomy and effective crop husbandry. It can be described as the combined application of compatible technologies that are tailored to farmers' needs, thereby improving crop productivity in an environmentally sustainable way. It is called by different names in different countries: Integrated crop and resource management in Indonesia and ICM in the Philippines. It combines the best of modern technology with some basic principles of good farming practice. ICM is a whole farm long term strategy and thus it cannot be applied to one crop or one field or one season. ICM involves multidisciplinary research and the basic components are soil management, crop rotation, crop protection, crop nutrition, wild life, landscape, energy, waste and pollution as well as organizational management. ICM offers particular advantages to small and marginal farmers as it reduces reliance on costly external inputs and encourages greater use of locally available farm resources. It follows a whole-farm, site-specific strategy that typically includes:

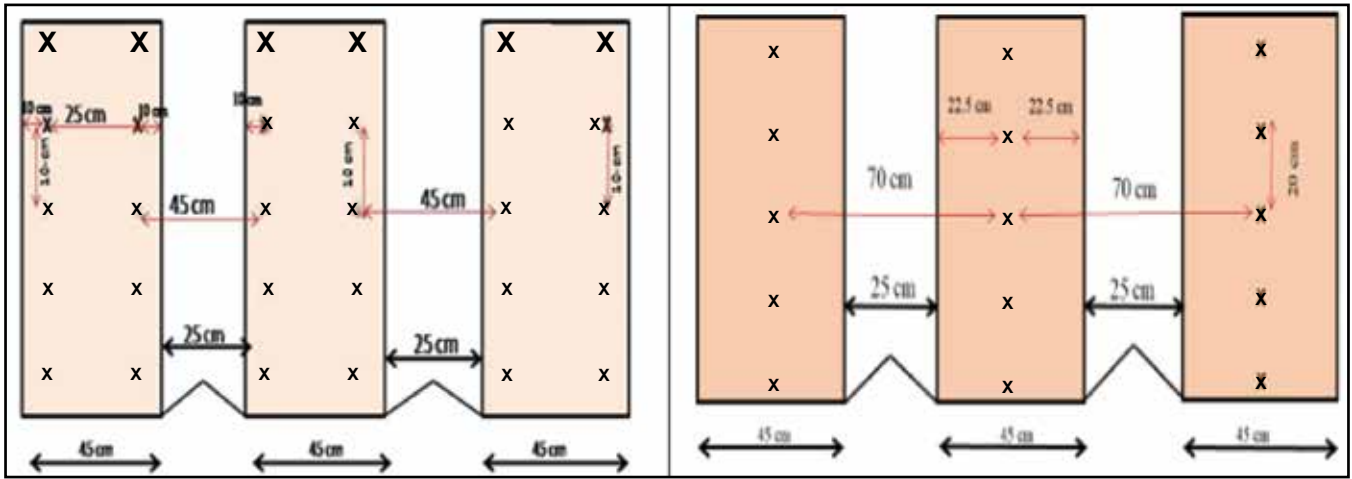
- Adoption of crop rotations to maintain soil fertility and break pest cycles
- Application of suitable tillage and cultivation methods
- Careful selection of crop varieties adapted to local conditions
- Reduced dependence on synthetic inputs such as chemical fertilizers, pesticides, and fossil fuels
- Protection and improvement of the farm landscape
- Promotion of wildlife-friendly habitats within the production system

Table 1. Key elements of integrated crop management

Component	Objective
Reduced tillage and soil conservation practices	Economical preservation of soil structure and long-term fertility
Application of biofertilizers, legumes, green manures, and agroforestry methods	Enrichment of soil fertility and enhancement of microbial activity and diversity
Integrated pest and disease management	Cost-effective and eco-friendly crop protection with minimal chemical residues
Crop diversification and rotational farming	Disruption of pest, disease, and weed cycles
Efficient utilization and safe disposal of crop and livestock residues	Recycling of resources to improve soil quality, plant health, and human well-being
Conservation and promotion of ecological diversity	Protection of soil health and preservation of biodiversity
Reduced dependence on external inputs and fossil fuels	Lower production expenses and minimization of environmental harm

Components of ICM

Basic components of ICM are tillage and crop establishment methods, INM, IWM, IWrm, IDM and IPM, efficient farm machinery management, energy management and even financial management.



Raised-bed land configuration and planting geometry for (a) Soybean and (b) Pigeonpea

Integrated crop management includes virtually everything that happens on the holding, including livestock management, where relevant.

Tillage management: Tillage and residue management play a vital role in crop growth, soil health, and sustainability. Tillage improves seedbed preparation, root development, and weed control, while long-term effects include maintaining soil productivity and conserving resources. India generates ~650 million tonnes of crop residues annually, with ~92 million tonnes burnt, causing pollution, nutrient loss, and health hazards. Continuous tillage degrades soil properties, whereas conservation tillage (reduced/no-till) improves soil structure, water conservation, SOC sequestration, and cropping intensity, while reducing GHG emissions. Thus, adopting suitable tillage and residue management practices is essential for sustainable crop production and environmental health.

Land configuration and crop establishment methods: Land configuration and crop establishment methods are crucial for soil productivity, water and nutrient use efficiency, and soil quality. Proper configurations improve soil biological activity, organic matter, and moisture while reducing erosion, runoff, and nutrient losses. Ridges warm and dry faster than flat-beds, influencing soil temperature and water dynamics. Suitable land configurations enhance crop growth and resource-use efficiency; for instance, soybean performs well on raised beds (70 cm wide) with two rows sown 25 cm apart on

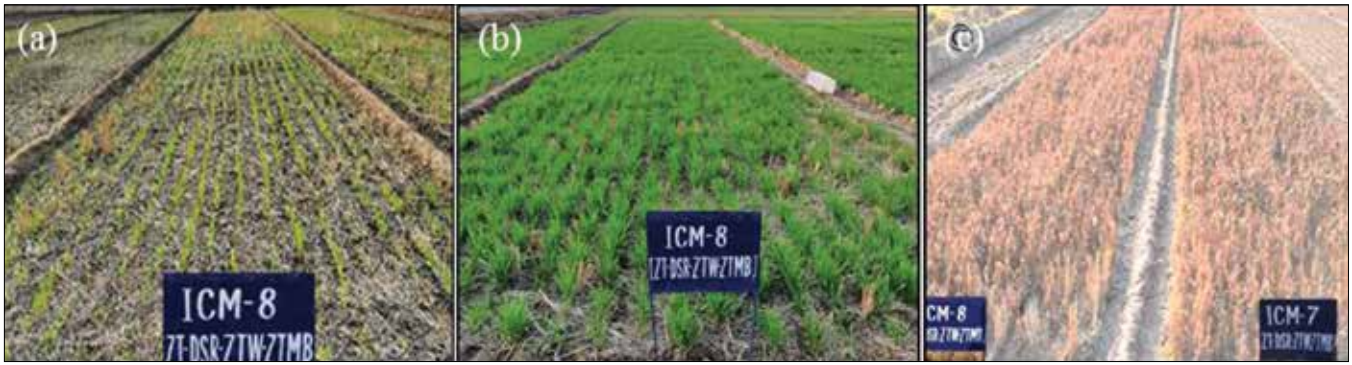
the platform and 10 cm spacing at edges and between plants. Such methods optimize productivity, soil health, and sustainability in cropping systems.

Integrated nutrient management (INM): Declining soil fertility and mismanagement of plant nutrients have made world's increasing demand for food a more difficult task. Adequate plant nutrient supply holds the key to better foodgrain production for sustaining livelihoods. Although a wide range of nutrient management strategies exist for different crops across the globe, many farmers fail to apply fertilizers at the recommended levels due to high costs and limited affordability. In this context, INM becomes vital emphasizing the combined use of organic manures, crop residues, green manures, biofertilizers, and legumes along with inorganic fertilizers to supply the nutrient requirements of various crops and cropping systems. Excessive reliance on chemical fertilizers alone has already resulted in environmental concerns such as soil degradation and contamination of water bodies. Hence, for achieving and maintaining higher crop productivity, the ICM approach must integrate INM with other complementary practices to ensure balanced and sustainable nutrient supply.

Integrated weed management (IWM): IWM refers to keeping weed populations at levels low enough to avoid significant economic loss in crops. It is a strategy that combines all feasible, safe, and cost-effective measures whether ecological, economic, or toxicological to ensure weeds remain below the Economic Threshold Level



Integrated crop management trials under a fixed maize-wheat rotation included: (a) Conventionally tilled plots following wheat harvest, (b) Plots with wheat residues retained, (c) Incorporation of mungbean as an additional crop, and (d) Incorporation of sesbania green manure within wheat residue-retained plots.



Integrated crop management rice-wheat rotation's experiment - (a) ZT direct seeded rice, (b) ZT wheat, and (c) knocked down mungbean

(ETL). The principle behind IWM is to apply multiple techniques in a coordinated manner so that crop yields are maximized at the lowest possible cost, while also considering environmental and socio-economic conditions of the production system. In practice, IWM adopts a long-term management perspective, drawing on diverse methods such as mechanical and manual removal, cultural and ecological practices, biological control agents, and judicious use of herbicides.

Integrated water management (IW_rM): IW_rM plays a key role in achieving sustainable agriculture. Although irrigated land accounts for only about 18% of the world's cropland, it contributes nearly 40% of total food production. However, irrigation efficiency remains poor, as just around 55% of the water applied is effectively used by crops, while competition for water continues to increase from domestic and industrial sectors. Improving water use efficiency (WUE) through practices such as conservation tillage, reduced tillage, and no-till farming helps conserve soil moisture, limit erosion, and support more intensive cropping, particularly in semi-arid zones. Moreover, making use of marginal water resources including saline, reclaimed, and drainage water alongside the adoption of advanced irrigation methods offers practical solutions to water scarcity and underpins sustainable crop production.

Integrated disease management (IDM): IDM is a holistic approach to reduce crop losses from pathogens (fungi, bacteria, viruses, nematodes, phytoplasmas) by combining cultural, biological, mechanical, and chemical methods. Unlike reliance on a single strategy, IDM emphasizes minimal pesticide use, prioritizing host-plant resistance, clean planting material, seed treatment, biological control, and good cultural practices. Modern crop protection products are increasingly target-specific and eco-friendly, reducing harm to beneficial organisms. Effective IDM requires crop rotation, farm hygiene, resistant varieties, natural predators, and precise chemical use. Wider adoption of IDM is essential to minimize 10–15% yield losses, enhance sustainability, and safeguard food security.

Integrated pest management (IPM): IPM is a sustainable strategy that combines cultural, biological, and chemical methods to manage pests while minimizing ecological disruption. Overreliance on pesticides has caused resistance, pest resurgence,

and residue problems, making IPM essential for food security. Traditionally, Indian farmers relied on cultural and mechanical practices before synthetic pesticides. IPM emphasizes predicting pest incidence, proper identification, and selecting effective, safe, and economical control measures. When chemicals are necessary, they must be used judiciously—choosing the right product, dose, timing, and application method. Training operators and integrating eco-friendly approaches ensures sustainable crop protection and reduced environmental impact.

Integrated energy management (IEM): IEM focuses on optimizing farm energy use for sustainability and profitability. Agriculture relies heavily on energy for tillage, irrigation, machinery, and inputs, yet efficiency often remains overlooked. Preparing crop-wise energy budgets and adopting renewable sources can enhance efficiency. Optimal energy input can raise yields by up to 30%, while conservation agriculture significantly reduces costs, as 25–30% of energy is spent on field preparation. Zero tillage with crop residue retention improves energy efficiency, soil health, and ecosystem services. Use of energy-efficient tools like seed-cum-fertilizer drills further lowers costs, boosts yields, and supports sustainable crop production.

SUMMARY

Integrated Crop Management (ICM) is a holistic approach that balances food production with environmental care, farmer welfare, and resource sustainability. Conventional farming practices have led to groundwater depletion, declining soil fertility, low resource-use efficiency, pest and disease resurgence, herbicide resistance, and environmental degradation. ICM integrates tillage, nutrient, water, weed, pest, and energy management to enhance productivity, profitability, and input-use efficiency while conserving soil, water, and energy. Despite its potential, systematic evaluation of ICM modules across crops and agro-ecologies remains limited. Developing region-specific ICM strategies is important to address resource vulnerabilities and climate change threats for sustainable agriculture.

*Corresponding author email: vpooniya@gmail.com