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Accounting of ecosystem services from climate-smart and efficient agricultural practices

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Agriculture produces more than food, feed and fibre. Climate-smart and resource-efficient practices can simultaneously improve farm productivity and profitability while conserving soil, regulating water, recycling nutrients, storing carbon and supporting biodiversity. These benefits, however, remain largely invisible in conventional farm accounts. Ecosystem services accounting provides a scientific pathway to measure changes in ecosystem condition and service flows before selectively estimating their economic significance. Indian evidence from climate-smart rice–wheat systems and long-term nutrient management experiments demonstrates measurable gains in resource-use efficiency, soil carbon and environmental performance. The Himalayan context adds a critical dimension on fragile slopes, soil conservation, spring and watershed regulation, agroforestry, traditional crop diversity and multifunctional landscape management that are as important as crop yield. India already has a foundation in ecosystem accounting; the next step is to connect it with agronomic evidence and region-specific farm monitoring.

Keywords: Carbon sequestration, Climate-smart agriculture, Ecosystem accounting, Resource use efficiency, Soil health

AGRICULTURAL success has traditionally been judged through yield, total production and private profitability. These indicators remain indispensable, but they do not capture the complete performance of a farming system. Agricultural landscapes also influence soil formation and erosion, carbon storage, water movement, nutrient cycling, biodiversity and microclimate. Better management can generate benefits that extend beyond the farm, while resource-intensive practices may impose environmental costs that are not visible in a conventional farm budget. The challenge for Indian agriculture is therefore not simply to produce more, but to produce efficiently while maintaining the natural resource base on which future production depends.

Climate-smart agriculture (CSA) provides a useful entry point because it seeks synergies among productivity and income, adaptation and resilience, and greenhouse gas mitigation. In practice, this involves portfolios of conservation agriculture, residue recycling, balanced and precision nutrient management, efficient water use, crop diversification, legumes, agroforestry and integrated farming. Their common feature is that they alter ecosystem condition through changes in soil cover, carbon inputs, nutrient cycling, water use and habitat structure. Ecosystem services accounting can make these changes visible and comparable.

Ecosystem services in agriculture

Agricultural land is a managed ecosystem in which soil, water, plants, animals and microorganisms interact. Provisioning services include food, fodder, fibre, fruits, fuelwood and other biomass. Regulating services include carbon sequestration, erosion control, water regulation, pollination and biological regulation of pests. Maintenance/Supporting functions include nutrient cycling, decomposition, biological nitrogen fixation and the maintenance of biodiversity. Cultural and social benefits may arise from traditional crop diversity, indigenous knowledge and the identity of agricultural landscapes.

A scientifically sound accounting system must distinguish ecosystem condition from final ecosystem services. Soil organic carbon, aggregate stability and biodiversity are primarily indicators of ecosystem condition or capacity. They may contribute to several services, but



Intercropping



Drip irrigation



Residue management



Crop diversification



Crop residue mulching



Agro-forestry

Different climate-smart and efficient agricultural practices

the same improvement should not be counted repeatedly as separate benefits. The preferred causal sequence is: management practice → change in ecosystem condition → change in ecosystem service flow → beneficiaries and benefits. This sequence also helps prevent double counting when monetary valuation is attempted.

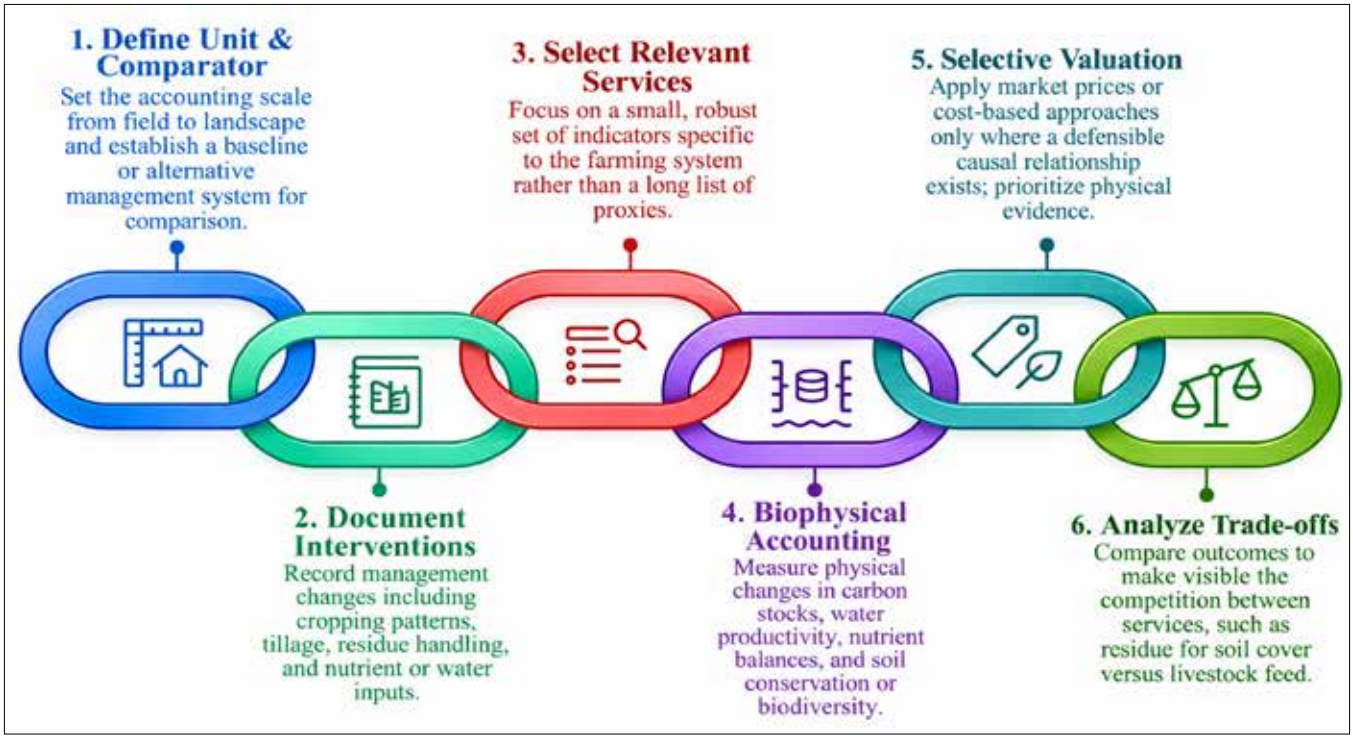
Climate-smart practices

Evidence from Indian cereal systems demonstrate the value of evaluating practices as portfolios rather than in isolation. Climate smart portfolios in rice–wheat systems have combined conservation agriculture, improved crop establishment, precision nutrient management and better water management. A synthesis of Indian work reported that layered climate-smart practices increased production by 8%, profit by 23%, total water productivity by 31% and energy productivity by 53%, while saving 24% irrigation water and reducing global warming potential by 40% compared with farmers' practice. These results show why ecosystem service accounting should be linked with productivity and profitability rather than treated as a separate environmental exercise.

A three-year on-farm study in the rice–wheat system at Karnal provided similar evidence. Compared with business-as-usual management, the climate-smart practice portfolio reduced global warming potential by 24% in rice and 65% in wheat while maintaining higher wheat and system productivity improved economic efficiency. Such results make the environmental contribution of improved management measurable. They also illustrate an important accounting principle that the relevant outcome is not simply lower input use, but the environmental impact per unit of land and, where appropriate, per unit of agricultural output.

Long-term nutrient management studies strengthen the soil health dimension. In semi-reclaimed sodic soils of north India, six years of integrating organic sources with balanced fertilisation increased soil organic carbon sequestration 1.5 times over balanced inorganic fertilisation and two times over farmers' practice. The same treatments improved nutrient availability while reducing fertiliser nitrogen and phosphorus requirements. In central India, a 43-year soybean–wheat experiment and modelling exercise showed that balanced nutrient management integrated with farmyard manure could reverse soil-carbon loss and increase carbon sequestration, although the response depended on nutrient rate, soil and the time required to approach a new steady state. These studies demonstrate that soil carbon accounting must be based on measured changes, depth, duration and local management rather than on a single universal coefficient.

The need for such an approach is even more compelling in mountain agriculture. In Uttarakhand, about 81% of agriculture in the mid- and high-altitude zones is rainfed, while irrigation availability in the hills is reported at only about 19%. Steep slopes, shallow and erosion-prone soils, rapid runoff and dependence on springs and local water sources mean that a field can have consequences far beyond its boundary. Recent state-level assessments show substantial variation in soil-loss tolerance across the Himalayan landscape and identify runoff-driven loss of fertile topsoil as a major threat to long-term productivity. Thus, in the Himalayas, soil and water conservation is not merely an input-saving practice, it is a central ecosystem service that underpins agricultural viability.



Ecosystem services accounting framework for agriculture

Ecosystem services accounting

A practical accounting framework for agriculture can be implemented in six steps. First, define the accounting unit and comparator. Depending on the question, the unit may be a field, farm, micro-watershed or landscape, and the comparator may be farmers' practice, a pre-intervention baseline or an alternative management system. Second, document the management intervention including cropping pattern, tillage, residue handling, nutrient and water inputs, trees, livestock and conservation structures. Third, select only those ecosystem services that are relevant to the farming system. A small, robust indicator set is preferable to a long list of poorly measured proxies.

Fourth, undertake biophysical accounting. Carbon can be measured as change in soil or biomass stocks and, where feasible, greenhouse-gas balance. Water-related accounting can include irrigation water applied, water productivity, runoff, infiltration or recharge-related indicators. Nutrient services can be represented by nutrient balance, nutrient-use efficiency and quantities of biomass or nutrients recycled. Soil conservation can be assessed through measured or modelled soil loss, while biodiversity can be represented through crop and tree diversity, habitat area and selected biological indicators.

Fifth, monetary valuation should be selective rather than automatic. Market prices can be used for marketed provisioning services. Avoided-cost, replacement-cost and production-function approaches may be useful when there is a defensible causal relationship between an ecosystem service and an economic outcome. However, monetary estimates should not replace physical evidence. In many cases, a scorecard

Table 1. Linking major climate smart practices with ecosystem service outcomes and accounting indicators

Practice	Major ecosystem service	Priority indicators
Conservation agriculture and residue retention	Soil cover, erosion control, improved soil condition, carbon retention and moisture regulation	Soil organic carbon, residue cover, infiltration, soil loss, microbial diversity, earthworm density, yield and energy use
Integrated and precision nutrient management	Nutrient cycling, improved nutrient-use efficiency and reduced nutrient losses	Nutrient balance, agronomic efficiency, partial factor productivity, recycled nutrients
Legume integration and crop diversification	Biological nitrogen contribution, diversified provisioning and greater resilience	Crop diversity, system yield, nutrient balance, microbial properties, and yield stability
Efficient water management	Improved water productivity and reduced pressure on water and energy resources	Irrigation water applied, water productivity and pumping energy
Agroforestry	Biomass and soil carbon, microclimate moderation, habitat and diversified products	Tree density, biomass carbon, soil carbon, canopy cover and product diversity
Integrated farming systems	Internal nutrient cycling, recycling and diversified production	Biomass/nutrients recycled, enterprise diversity, beneficial insect, pollinators, pesticide residue, external-input dependence and net returns

combining biophysical and economic indicators will be more credible than forcing every ecological process into a rupee value. Sixth, compare outcomes and trade-offs. Residue retention may improve soil cover but compete with livestock feed; trees may enhance carbon and biodiversity but compete with crops for light or water; and water-saving technologies may require capital or specialised management. Ecosystem accounting is valuable precisely because it makes these multiple outcomes visible.

Indian perspective and way forward

India already has an institutional foundation for ecosystem accounting through the Natural Capital Accounting and Valuation of Ecosystem Services initiative and SEEA-based ecosystem accounts, including cropland-related extent, condition and service information. The next step is to connect these national accounts with agricultural experiments, climate-smart villages and farm monitoring. Agronomic research already measures yield, profitability, soil properties, water use, nutrient efficiency and, increasingly, greenhouse gas footprints. These datasets can be reorganised around a common accounting question on what changed in ecosystem condition, what service flow changed, who benefited and how should the change inform management or policy? A national framework should contain a common core of soil organic carbon, selected soil-condition indicators, nutrient balance and efficiency, water productivity or water use, erosion risk, greenhouse gas performance where feasible, and practical biodiversity indicators plus agro-ecological modules. The Indo-Gangetic Plains may emphasise water, energy, nutrient efficiency, residues and GHG intensity. Drylands may prioritise soil moisture and erosion. Coastal systems may require salinity and water-quality indicators. For the Himalayan region, a dedicated module should prioritise:

- Soil loss relative to local soil-loss tolerance
- Runoff and water harvesting
- Spring or local-source water availability where relevant
- Soil organic carbon and terrace condition
- Tree and perennial vegetation
- Crop and enterprise diversity
- Farm-level provisioning and livelihood outcomes.

Monitoring should combine field measurements with GIS and remote sensing, but hydrological and soil indicators require ground-based validation. A network of long-term reference sites, climate-smart villages and micro-watersheds would allow robust coefficients to be developed before large-scale incentive schemes are introduced.

The UNEP–TEEB framework can complement ecosystem service accounting by helping translate evidence into policy. It encourages recognition of ecosystem service benefits and costs, their demonstration through biophysical and, where appropriate, economic evidence, and their integration into agricultural planning, public investment and incentive mechanisms. Thus, while the proposed accounting framework provides the measurement base, TEEB can guide the use of this evidence in climate-smart agriculture and natural-resource policies. Farmer incentives should follow measurement, not precede it. Payments for ecosystem services, carbon-linked support or water-conservation incentives require credible baselines, additionality and verification. Collective approaches through farmer groups, producer organisations or watershed institutions may reduce transaction costs, particularly where ecosystem services are generated collectively across a landscape.

SUMMARY

Climate-smart and resource-efficient agricultural practices should be evaluated for the multiple outcomes they generate. Indian evidence shows that well-designed practice portfolios can improve productivity and profitability while enhancing water and energy productivity, soil organic carbon and environmental performance. Ecosystem services accounting can make these benefits visible by linking management practices with changes in ecosystem condition, service flows and beneficiaries. The most practical approach is to begin with biophysical indicators and use monetary valuation only where the evidence and purpose justify it. India already has a national foundation through SEEA-based ecosystem accounting and cropland accounts. The next step is to connect these efforts with agronomic experiments and farm-level monitoring through a small, region-specific set of indicators. Such accounting can improve comparison of agricultural systems and eventually support credible incentives for farmers who deliver measurable environmental benefits.

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