ECOSYSTEM SERVICES VALUATION UNDER CONSERVATION AGRICULTURE

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Agricultural intensification has enabled the unprecedented increases in global food production, yet conventional tillage-based cropping systems have simultaneously degraded the natural capital upon which long-term productivity depends. Conventional management practices have accelerated the soil organic matter depletion, increased the erosion vulnerability, and diminished the regulating ecosystem services essential for system resilience. The challenge faced by agricultural science and policy is to transition towards the production system that maintains or enhances the yield while restoring the biophysical foundations of sustainable agriculture.

CONSERVATION AGRICULTURE: A PATHWAY TOWARDS THE SUSTAINABILITY

Conservation Agriculture (CA), which is founded on the three pillars of minimal soil disturbance, permanent soil organic cover, and diversified crop rotations, has emerged as a critical strategy for enhancing the sustainability of global agri-food systems. Among these systems, the soybean-wheat (Glycine max L.-Triticum aestivum L.) rotation is increasingly recognized for its potential to replace more resource-intensive cereal-cereal systems, particularly in regions like the Indo-Gangetic Plains (IGP) where continuous rice-wheat cropping has led to soil degradation and water depletion (Pathak et al., 2017). By integrating legumes into the rotation, CA practices in wheat-soybean systems not only maintain the productivity but also bolster a wide range of ecosystem services (ES) that are often overlooked in traditional economic assessments.

VALUATION OF ECOSYSTEM SERVICES: A MULTI-FUNCTIONAL APPROACH

As per the Millennium Ecosystem Assessment (2005), ecosystem services are *the benefits people obtain from the ecosystems*. Figure 1 explain the four categories of ecosystem services delineated in the report, i.e., provisioning services, supporting services, regulating services, and cultural services. Ecosystem services in agricultural landscapes encompass direct and indirect contributions of ecosystems to human well-being, categorised into provisioning (food, fiber), regulating (carbon sequestration, pest control), supporting (nutrient cycling, soil formation) and cultural services.

Monetary Quantification:

While provisioning services are easily quantified through market prices, regulating and supporting services such as the nitrogen-fixing capacity of soybean or the carbon storage potential of zero-tillage under wheat remain "non-traded" and undervalued (Sandhu et al., 2015). The shift toward multi-functional agriculture needs a transition from evaluating systems solely based on grain yield to assessing their broader environmental and social impact.

The monetary quantification of these services is essential for aligning the farm-level decisions with regional and global sustainability goals. Valuation provides a common language for policy-makers, enabling the design of the incentive structures similar to that of Payments for Ecosystem Services (PES) syetm. Methodologically, the valuation of these services relies on the various economic approaches. Market-based methods are used for tangible outputs, while non-market techniques like the replacement cost method (e.g., valuing soil nutrients by the cost of equivalent chemical fertilizer) and stated preference methods (e.g., willingness to pay for improved water quality) are employed for regulating services. The selection of an appropriate valuation method is contingent upon the specific ecosystem service under evaluation and the socio-economic context of the study area.

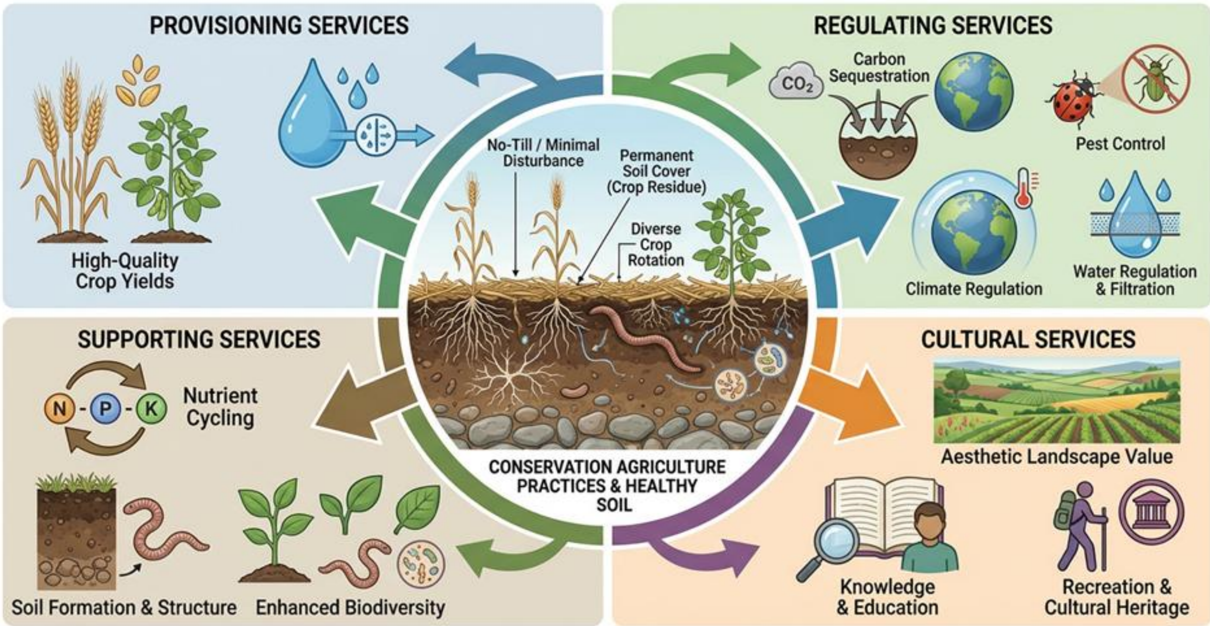

Figure 1. Ecosystem Services under Conservation Agriculture

Empirical evidence demonstrates that CA practices enhance multiple ecosystem services simultaneously. For example: zero tillage with residue retention increases the soil organic carbon (SOC) accumulation, improves water regulation, reduces erosion, and supports beneficial soil biodiversity. By translating critical ecological functions such as carbon sequestration, enhancement of soil fertility, water regulation, erosion control, and biodiversity conservation into monetary terms, this approach elucidates the economic feasibility and sustainability advantages inherent in conservation agriculture practices. Such quantification not only underscores the direct and indirect economic benefits but also facilitates the integration of ecosystem services into agricultural management and policy frameworks, promoting the adoption of environmentally sustainable practices. Sandhu et al. (2015) estimated that the value of non-traded services like nitrogen mineralization can range from US$60 to over US$400 per hectare annually, depending on the intensity of conservation practices.

In long-term maize-wheat systems under CA, regulating ecosystem services have been reported to increase by 61.1% compared to conventional tillage, with SOC accumulation accounting for approximately 90–91.6% of the regulating service value (Mandal et al, 2025). These biophysical improvements translate into measurable changes in supporting and regulating services that underpin long-term farm productivity and landscapescale environmental quality. Studies in Central India's Vertisols have shown that long-term NT can store up to 14% more SOC than conventional inversion tillage over a 15-year period (Lenka et al., 2015).

Pathak et al. (2017) introduced the concept of "Green Income", defined as the sum of conventional net farm income, monetized ecosystem service benefits, and subtracted ecosystem dis-service costs (e.g., environmental pollution or soil erosion), provides a comprehensive metric for evaluating the true economic performance of alternative management systems.

On-farm studies in wheat systems have demonstrated that Green Income under zero tillage with residue retention (53,493 per ha) substantially exceeds that under conventional tillage (33,358 per ha), reflecting both higher aggregate ecosystem service values (75,253 vs. 68,381 per ha) and reduced dis-service costs (1,009 vs. 1,072 per ha) (Pathak et al., 2017).

These findings show how incorporating environmental externalities into farm-level accounting reveals economic advantages of CA that remain invisible in conventional profit calculations. Their research on wheat-based systems demonstrated that while conservation practices may involve initial transition costs, the long-term "Green Income" often exceeds that of conventional tillage due to significant gains in soil fertility and water regulation.

MAJOR CHALLENGES IN THE MONETARY QUANTIFICATION OF ECOSYSTEM SERVICES

Nevertheless, the process of monetary valuation is accompanied by several challenges. Methodological constraints arise from the complexity of ecosystem functions and the difficulty in isolating individual service contributions. Furthermore, environmental variability, such as differences in climate, soil type, and landscape characteristics, alongside socio-economic factors like market fluctuations and stakeholder preferences, introduce significant heterogeneity into the valuation outcomes.

Additionally, inherent uncertainties exist in capturing the full spectrum of ecosystem service values, particularly for non-market and intangible services, which may lead to underestimation or overestimation of benefits.

Along with the above challenges, India's nascent carbon market also present a challenge as carbon credit is sold at lower price in Indian exchange market than international market which reduces the incentive for farmer to adopt sustainable practices.

ECOSYSTEM SERVICES VALUATION: UTILITY

Despite these challenges, the importance of economic valuation extends beyond academic interest and has significant implications for agricultural policy and sustainable development.

- Monetary estimates provide the empirical foundation for designing PES schemes that compensate farmers for adopting practices that generate positive environmental externalities; case studies report typical compensation estimates of US$271.6 per ha yr^{-1} to encourage agro-ecosystem service provision.
- Valuation enables cost-benefit analysis of Conservation Agriculture promotion programs, allowing policymakers to compare investment costs against the full spectrum of social benefits.
- Green Income accounting empowers farmers and extension services to make informed management decisions by revealing the medium- and long-term economic advantages of CA that are obscured by conventional financial metrics.
- Transparent valuation supports the integration of agriculture into broader environmental accounting frameworks, including natural capital assessments and national ecosystem service inventories.

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