

Abstract

Agricultural intensification is a principal driver of terrestrial biodiversity loss globally, yet the ecological cost embedded in crop production systems remains largely absent from economic evaluation and policy instruments in South Asia. This study develops an integrated, farm-level framework that quantifies the shadow price of biodiversity loss attributable to the production of Pakistan's three major crops including rice, cotton and wheat. A three-stage methodology is employed. In Stage 1, a Directional Distance Function (DDF) within a Data Envelopment Analysis (DEA) framework is used to estimate farm-level productive efficiency and input shadow prices from a survey of crops across the Indus Basin canal commands. In Stage 2, a Biodiversity Loss Index (BLI) is constructed independently for each farm using endpoint characterization factors from the ReCiPe 2016 life cycle impact assessment method, translating fertilizer, pesticide, irrigation water and energy inputs into biodiversity loss in potentially disappeared fraction per year per hectare (species·yr/ha). In Stage 3, the DEA-derived shadow prices and BLI characterization factors are integrated to compute three policy-relevant metrics: the input-specific biodiversity shadow price, the farm-level Shadow Value of Damaging Inputs (SVDI) and the synthetic farm-level biodiversity shadow price index. Using 2025/2026 Pakistan market prices, results show that shadow prices of inputs exceed observed market prices for 70–100% of farms across all crops, a pattern consistent with Category II dominance and with subsidized input markets. This pattern indicates a private incentive to expand input use given current prices, rather than direct proof that inputs are currently over-applied. These findings demonstrate that farming systems are imposing a substantial pressure on biodiversity which is currently unpriced, and vary meaningfully across crops and ecological damage pathways, providing an empirical basis for biodiversity-sensitive agricultural policy reform in Pakistan and comparable agrarian economies.

Keywords: *shadow pricing; biodiversity loss; DEA-DDF; ReCiPe 2016; Pakistan; wheat; rice; cotton; Indus Basin*

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