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Scientific and Theoretical Approaches Dedicated to Agriculture Support on the Basis of the Principles of Innovation Management

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Abstract

This article examines the current state of scientific and theoretical views on supporting the agricultural sector based on the principles of innovation management, and also analyzes the experience of some countries. Based on the results of the analysis, conclusions were developed based on some scientific and theoretical views.

Keywords: *innovation, innovative technologies, agriculture, public sector, society.*

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Introduction

In recent decades, large swaths of the developing world have seen unprecedented growth in food production. Due to the advancement of Green Revolution technologies and the widespread adoption of high-yielding varieties of staple foods by, for example, Asian farmers, famines in that region have been averted, hunger and malnutrition have decreased, and many countries have achieved near-self-sufficiency. Environmental benefits are also significant: sustained yield increases have helped avoid overexploitation of marginal land and slowed the rate of deforestation.

Several concerns, however, remain. In Sub-Saharan Africa, where hunger is on the rise, new agricultural technologies have had little success. Significant pockets of poverty continue to exist in areas characterized by rain-fed agriculture or fragile soils, affecting nearly a billion people. Yield growth in high-external-input systems has slowed, serious environmental problems have emerged, and land and water constraints constrain the expansion of irrigated agriculture. As a result, several high-potential areas exhibit diminishing marginal returns on further intensification, which frequently falls short of the potential returns associated with developing more fragile land (Hazell and Fan, 2000).

A significant challenge for the coming decades will be the development of technologies and practices that enable agriculture to continue growing in order to meet the growing demand for food and feed. To alleviate rural poverty and hunger, agricultural growth must be equitable and designed in such a way that the natural resource base is preserved and pollution is minimized. Hazell and Lutz (1998) demonstrate that this type of agricultural development is broad-based, market-oriented, participatory, and decentralized, and is fueled by new approaches to agricultural innovation that increase factor productivity while conserving the resource base. To mitigate excessive reliance on external inputs, there is growing interest in agroecological approaches that emphasize promoting favorable growing conditions for plants and animals within a larger ecosystem (Altieri, 1995). The latter system emphasizes diversification of activities, interaction between cropping, livestock, and forestry, biological pest and disease control, and soil erosion and nutrient depletion management.

The advantages of alternative systems are frequently quantified in biophysical terms (soil organic matter, physical yields). The welfare implications for farm household income, consumption, and labor use receive far less attention. We propose the term "Sustainable Agricultural Intensification" to encompass both protection of the natural resource base necessary to maintain soil nutrient balances and land productivity, and efficient combinations of production factors that increase farm household income, including labor returns. Given the likelihood of trade-offs between agroecological and welfare criteria, we focus on "win-win" technologies that enable simultaneous improvement on both fronts. However, such improvements are unlikely to be shared equally among all farm households. Households have varying levels of access to resources, markets, knowledge, and information, and this unequal access to resources, markets, knowledge, and information can be a source of economic and social concern.

This section examines the environmental, economic, and social consequences of more sustainable technologies in developing economies. Due to the fact that empirical evidence on sustainable farming systems is still scarce and frequently insufficient, we focus on the ex ante assessment and potential policy implications of new SAI approaches. Following some general observations about agricultural productivity growth and sustainable land use, five criteria for evaluating SAI systems and their potential adoption are proposed. The impact of such new systems is briefly discussed. We then address the policy issue of how to foster the adoption of promising sustainable farming approaches. The concluding section synthesizes these and other findings.

Productivity and sustainability

Increased productivity

Agriculture plays an intriguing and seemingly paradoxical role in the process of development. At low per capita income levels, rapid productivity growth is required to improve rural incomes and maintain food supplies for urban populations, raw material supplies for ago-industrial development, and crash crop production for export earnings and taxes. Agriculture's contributions to economic development require a well-defined policy framework that provides farmers with appropriate incentives to increase productivity sustainably while reducing past demand for public expenditures.

Increased income, as a result of increased factor productivity, results in a shift in consumption expenditures away from food. While agricultural productivity increases continue to be significant, agricultural output typically expands at a slower rate than the majority of other economic activities. As a result, agriculture's statistical importance in the macroeconomy declines, a process accelerated by the rapid adoption of more productive technologies. The fact that agricultural productivity growth and relative size decline occur concurrently has frequently confounded policymakers.

The agriculture sector's response to policy measures is largely based on supply response analysis (particularly relative prices for agricultural inputs and outputs, trade and exchange rate policy, availability of public goods and services, and access to markets and information). Supply response can take the form of area expansion, technology advancement, or crop substitution, all of which have quite distinct implications for resource allocation and the environment. Responses will vary between different types of rural households (i.e., according to their resources and risk attitudes) and may be delayed due to differences in expectations and adjustment costs. Household heterogeneity, particularly in terms of access to markets, knowledge, and information, is thus a significant source of differential technology adoption and income-earning opportunities.

Land use that is sustainable

The empirical evidence regarding the impact of agricultural policies and structural adjustment on land use sustainability is inconclusive. According to some authors, price reforms will exacerbate soil depletion, while others assert that they will increase farmers' investment in soil conservation activities (Barrett, 1991, provides a summary of the arguments). These divergent views on the relationship between prices and soil degradation stem from disagreements over how discount rates and relative risk aversion are specified. Additionally, market imperfections may obstruct the transmission of higher output prices to farm household consumers.

Four distinct possible response reactions to changes in relative prices on agricultural resource allocation can be distinguished: I area expansion (extensification); (ii) increased input use (intensification); (iii) technological change (input substitution); and (iv) crop choice adjustment (output substitution). It is necessary to distinguish between cost adjustment (productivity-enhancing investment) and investment in fixed assets to prevent further soil deterioration (i.e.

terraces, windshields, etc.).

Typically, supply response reactions to changing relative prices are analyzed in terms of substituting fertilisers for the nutrients lost from natural sources due to soil loss. Alternatively, natural soil fertility is treated as a function of capital and/or labor investments in conservation measures. Both of these factors are typically scarce, particularly in African agriculture. Soil mining practices appear to be a recurring occurrence, and promoting sustainable land use requires complementary strategies for selective intensification and soil conservation measures that increase productivity.

The relationship between agricultural policies, farmer supply responses, and the resulting implications for sustainable land use is not completely understood. When agricultural production increases as a result of area expansion, environmental consequences such as deforestation, overgrazing, erosion, and sedimentation are to be expected. According to Binswanger et al. (1987), an increase in output prices results in an increase in area but only a small increase in yields. Area expansion may be compatible with improved land use if cropping activities are shifted concurrently, with the final effect dependent on the negative effects of cropping activities on resource (i.e. soil) quality. Generally, the complementary effects of input use on chemical or physical soil properties are ignored. As a result, changes in the efficiency of inputs (fertilisers and labor) as a function of soil organic matter content or soil conservation investments are not adequately captured. Further examination of these issues will necessitate the development of a more detailed framework based on the relationship between welfare and sustainability effects.

Profitability

Farmers will adopt sustainable agricultural technologies and practices only when their income and consumption opportunities increase and become more stable. Profitability requires the presence of efficient market outlets as well as favorable output/input price ratios. Market distortions or inefficient exchange networks reduce the incentives for soil conservation activities to be undertaken. Agricultural intensification may become unsustainable if farmers continue to cultivate subsistence crops and rely almost entirely on locally sourced resources. Lockeretz, 1989; Low, 1993).

Contrary to popular belief, farmers are more likely to use inputs that increase yield and improve sustainability in commercially oriented production activities (Reardon et al., 1999; Putterman, 1995). Chemical fertilisers, crop residues, and animal manure are frequently used in southern Mali and Burkina Faso's cotton belts for cash crops that provide sufficient monetary returns to justify these costs (Sissoko, 1998; Savadogo et al., 1998). Similarly, when applied to more fertile fields where commercial crops are grown, animal traction and improved tillage yield higher returns. Crop residue mulching appears to be profitable in Mexico's Central Chiapas region only when combined with animal traction on fields devoted to intensive market-oriented cropping activities (Erenstein, 1999).

Thus, farmers' participation in the market can be viewed as a necessary condition for profitable and sustainable agriculture. Trade enables the acquisition of complementary inputs and consumption goods. Low commodity prices benefit households that maintain a net demand position on the food market. Where formal credit services are unavailable, investments can be financed through earnings from off-farm employment (Ruben and van den Berg, 1999). Market development may increase farmers' willingness to invest, whereas market participation generally increases farmers' responsiveness to price incentives. As a result, when market failures persist, policy reforms remain the first line of defense. Without them, increasing reliance on low-external-input technologies is a common outcome.

Efficiency of input

The prospects for sustainable agricultural intensification are contingent on the ability to increase input efficiency, as measured by the marginal returns on an additional unit of (organic or inorganic) inputs. Production ecology approaches emphasize the importance of nutrient efficiency (i.e.

The availability of complementary micro- and macronutrients, most notably soil organic matter and phosphorus, determines uptake (Van Keulen, 1982). Chemical fertiliser alternatives generally have a low recovery fraction due to nutrient immobilisation and slow decomposition of organic matter.

Nutrient recovery and uptake efficiency can be improved by I soil and water conservation measures that decrease the soil's nutrient retention capacity, and (ii) frequent nutrient applications based on crop growth process timing (e.g. shortly after sowing and with sufficient rainfall). Both activities require a great deal of labor but are difficult to automate. Furthermore, mechanical or animal tillage accelerates the release of nutrients from the soil.

Agricultural yields are highly dependent on the most constraining factor and can only be increased when input combinations that ensure adequate synergy effects based on strict complementarity between different growth-enhancing inputs are made available (i.e. nutrient and water, phosphorus-nitrogen, and carbon-nitrogen ratios). Studies on input efficiency focus on the functional relationships between soil carbon content and (in)organic nitrogen supply in order to avoid nutrient immobilisation, as well as the proportional relationship between nitrogen and phosphorus in order to ensure an adequate decomposition rhythm (Penning de Vries and van Laar, 1982). This implies that when complementary inputs are not available at the right time or in sufficient quantity, input efficiency tends to be low.

Farmers have long recognized the value of combining diverse productive activities to create beneficial synergy effects. Organic and chemical inputs are not perfect substitutes, and often the best results are obtained by combining locally available resources with selectively applied external inputs. In practice, farmers are hesitant to completely abandon purchased inputs because they allow for better scheduling of activities, reduce labor demand during critical periods, and contribute to the appearance of the produce on the market. Due to the low nutrient content and delayed availability of nutrients in organically produced fertilisers (green manure, mulch, dung, and compost), chemical fertilisers cannot be completely eliminated. Because organic matter decomposition is a slow process, optimal results are obtained by gradually reducing chemical fertiliser applications to a minimum level.

If sufficient phosphate is available, nitrogen derived from cover crops via biological fixation can be made more effective. Due to the fact that tropical soils are typically deficient in phosphorus, applying phosphate fertiliser or rock phosphate will aid in increasing overall input efficiency (Kuyvenhoven et al., 1998a). Similarly, nitrogen is most effective when combined with a small amount of water and organic matter. Where reliance on internal inputs alone compromises nutrient efficiency, selective use of complementary external inputs should be encouraged (Triomphe, 1996; Buckles et al., 1997). Similar complementarities exist in integrated pest management (IPM) programs, where improved nutrient application is a primary tool for pest and disease control. Farmers who use low levels of chemical fertilisers experience significantly less crop loss due to competition or infestation. Without fertilisers, diseases easily spread into fields, whereas with high doses of fertilisers, weeds become a threat to yields.

Substitution of factors

The majority of analyses of natural resource management practices focus exclusively on short- or long-run yield effects and provide no indication of labor requirements or returns to labor. Thus, implicitly, family labor is regarded as a 'abundant' resource. While technical efficiency is typically measured against the most constraining factor affecting yield growth (i.e. water, nutrient, energy, pests, and diseases), economic efficiency should be determined by an examination of critical factors affecting farm household income (land, labour, capital, knowledge). Additionally, certain constraints on the possibility of substituting labor for external inputs should be recognized.

Sustainable agroecological practices are typically labor intensive. Physical soil conservation measures promoted in Central American hillsides and West African lowlands have resulted in modest yield increases, but require considerable labor for construction and maintenance, as well as significant costs for material acquisition and transportation (Stocking and Abel, 1989). Given their high labor intensity and lengthy gestation period, such measures' returns to labor are frequently critical (Lutz et al., 1994; de Graaff, 1996). Green manure practices and crop residue mulching, on the other hand, require additional labor for harvesting, transportation, and under-ploughing (Ruben et al., 1997; Erenstein, 1999). Due to high establishment, maintenance, and harvesting costs, the majority of mixed cropping and agroforestry systems have low returns on labor (Current et al., 1995). While growing fodder crops for livestock feed increases manure availability for arable cropping and enables farmers to recycle crop residues, both activities require significant additional labor (Breman and Sissoko, 1998). Labor requirements for integrated pest and disease management are also high, owing to the elimination of manual operations in favor of chemical ones. Due to the steep terrain slopes and small scale of operations, mechanisation is not an option for the majority of these natural resource management practices.

To conduct a systematic assessment of the attractiveness of natural resource management practices from the perspective of farm households, returns to land and labor must be compared concurrently (Reardon, 1995). Marginal returns must be considered in comparison to other activities (i.e. off-farm employment; hiring-out of land). Even when sustainable agroecological practices increase nutrient stocks and soil organic matter content, the yield increase is typically negligible in comparison to the increased input requirements. This can be explained by the fact that labor is required to ensure the cropping system receives nutrients on time. As a result, labor returns are frequently outweighed by conventional technologies, which are predominately based on input complementarities.

The figure 1 summarizes the major practices of natural resource management, taking into account expected yield effects and labor requirements. The farmer's final choice of natural resource management practices is likely to be determined by the labor/output price relationship. The best results on both counts are obtained through soil fertility enhancement measures, followed by mixed cropping and minimal tillage. Soil and water conservation measures, as well as intensive weeding, are attractive for high-value-added cropping activities and in situations where labor costs are low.

The high labor intensity of the majority of farm management practices is a significant impediment to adoption. Labor is typically scarce in semi-arid areas during the soil preparation, weeding, and harvesting phases, and competition for labor intensifies when mulching, manuring, or crop residue recycling are implemented. Otherwise, resource-scarce farmers are likely to derive a portion of their income from off-farm activities that must be reduced as their farming system is intensified through labor (Reardon et al., 1988). Farmers are likely to make changes to their production system only when the additional income generated by those activities is more favorable than the opportunity cost of labor. Other farm management practices, most notably physical soil conservation, can be carried out during the off-season, but they consume time that could be used for social or communal activities.

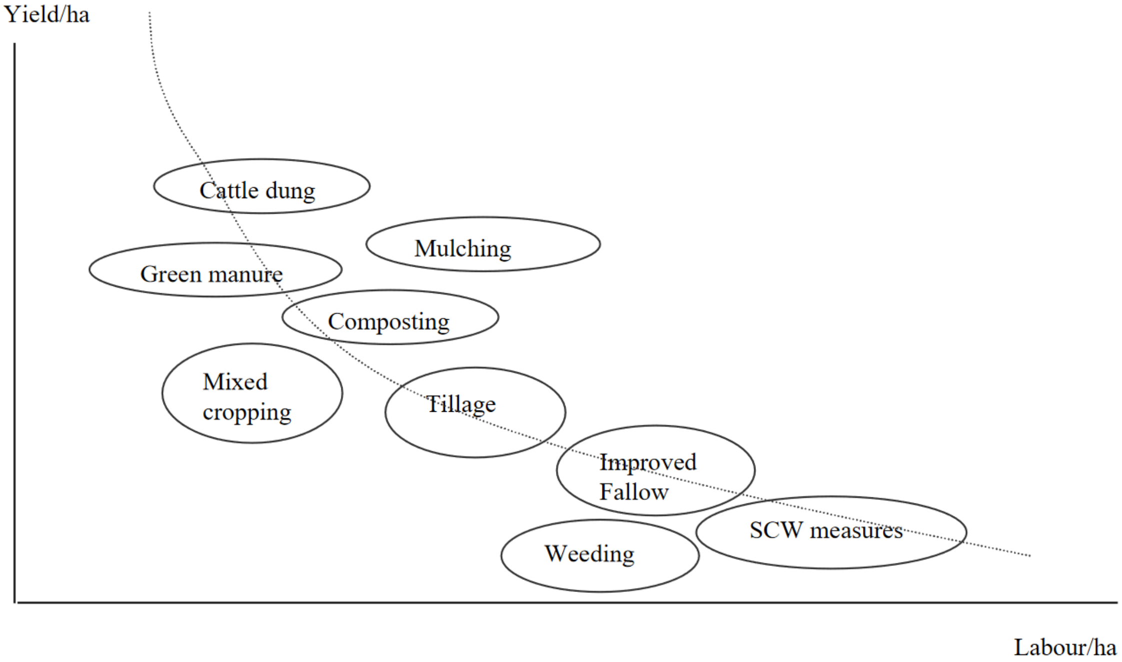

Figure 1. Factor intensity and yield effects of major farm management practices

Management of risks

Farmers with limited resources are more likely to rely on fairly diverse patterns of activity to ensure adequate risk management. Diversification of crop and livestock production, as well as their integration with (ago)forestry, aquaculture, and improved fallow practices, can help farm systems become more resilient through nutrient recycling, biodiversity management, and integrated pest and disease control (Muller-Samann and Kotschi, 1994). As a result, yields are more stable and reliance on purchased inputs can be reduced.

However, it is becoming increasingly recognized that risk management can also occur through farmers' involvement in off-farm and non-farm activities (Reardon et al., 1994). The revenue streams generated by these activities are significantly less dependent on changing weather conditions and thus provide adequate protection against covariate shocks (Udry, 1990). Along with diversification of cropping systems, diversification into non-agricultural activities can be considered a risk management strategy. Reliance on this strategy becomes feasible when agricultural labor demand can be reduced and household members have the necessary skills and knowledge to enter wage labor or self-employment (Reardon, 1997).

Another aspect of short-term risk management is farmers' ability to adjust their input use in response to changing weather or environmental conditions. Adaptive behavior is highly dependent on the capacity for learning that enables rapid responses to unexpected events (Fujisaka, 1994). While the majority of agroecological practices have been developed through participatory and horizontal extension methods (e.g., farmer to farmer approach; farmer field schools), there is a relatively limited understanding of production system dynamics. A case in point is Honduras' abandonment of maize-cover crop systems, which can be attributed to an insufficient response to weed invasion and subsequent abandonment of'companion technologies' such as live barriers, contours, crop residue recycling, and reseeding (Neil and Lee, 2000).

Sustainability

SAI implies that the resource base's production capacity can be maintained in the long run. This does not necessarily imply that agroecological balances should be strictly maintained at all times. Farmers may, in principle, allow resource depletion in the short run while investing in resource recovery in subsequent periods. The term "weak' sustainability" (Pearce and Turner, 1990) is frequently used in economic analyses of land use systems.

Typical instances of 'optimal depletion' occur in traditional fallow systems that are allowed to recover following a period of continuous exploitation. Natural regeneration can occur in a similar manner for wildlife species, fisheries, and forest systems (Bulte, 1997). For given prices and discount rates, an optimal composition of the renewable resource stock that meets intertemporal welfare criteria can be determined. As a result, it may be economically rational to reduce stocks in the short run and reserve investment funds for their eventual recovery.

Farmers' preference for substandard sustainability can be explained in terms of trade-offs. Discounting procedures that reflect farmers' relative time preferences are used to compare current and future costs and benefits. Individuals exposed to greater risk have a higher discount rate, which reflects their preference for immediate revenue. As Current et al. (1995 demonstrate for agroforestry projects, investment activities with long gestation lags are particularly sensitive to high discount rates.

A second type of trade-off occurs when farmers weigh the benefits and implications of alternative technologies for animal welfare and sustainability (Kruseman et al., 1996). Farmers' adoption of sustainable practices can be expected only when there are positive welfare consequences. However, in practice, agroecological sustainability frequently entails a trade-off in terms of income or consumption goals. Furthermore, while production systems may become sustainable at lower system levels (field, farm), they may retain externalities at higher system levels (village, region). In such cases, (agrarian) policy instruments can assist in resolving trade-offs, and appropriate incentives should be identified that promote both welfare and sustainability simultaneously (“win-win” scenarios; Kuyvenhoven et al., 1998b).

Impact assessment

The majority of empirical studies on the efficiency of sustainable practices and technologies are yield- and resource-balance-oriented. Positive returns on land are frequently regarded as a sign of financial viability. However, an economic assessment of their attractiveness from the perspective of a farm household requires the consideration of additional criteria. Different (combinations of) analytical methods can be used in accordance with the five criteria that govern the socioeconomic evaluation of agricultural technologies and production systems (Ruben et al., 2000).

Profitability of agricultural intensification can be quantified fairly easily using conventional cost-benefit analysis (CBA). However, it should be recognized that profitability is a necessary but not sufficient condition for adoption, as it ignores non-income farm household objectives. CBA assesses average costs and revenues at current prices, typically using a partial equilibrium framework. It is primarily used to assess specific natural resource management practices such as soil and water conservation, crop residue mulching, and agroforestry systems. Apart from revenue, objectives can be considered by extending CBA to multi-criteria analysis (MCA). However, its partial nature is typically retained.

To conduct a thorough analysis of input efficiency, it is necessary to have information about the marginal returns on factors of production. As a result, production function analysis (PFA) serves as an effective analytical framework. PFA enables the estimation of marginal returns to land and labor for agroecological and conventional production technologies, as well as the identification of the range of input-output price ratios at which conversion is likely to occur. Additionally, characteristics of typical farm households associated with the adoption of sustainable technologies can be revealed.

A comprehensive examination of the economic attractiveness of sustainable technologies in light of the prospect of factor substitution necessitates the use of farm household modeling (FHM). Farm household models explicitly account for input complementarities and provide an analytical framework for evaluating both production and substitution effects concurrently. Market linkages and general equilibrium effects are also included in further extensions to village-wide models. FHM provides useful policy simulation procedures for assessing farmers' supply response to various types of economic incentives.

Risk management considerations can be incorporated into programming models and econometric procedures. Explicit assessment of farmers' risk behavior and coping strategies, on the other hand, requires a separate treatment. Thus, portfolio analysis can be used to assess the variability of household income across different income categories (farm, off-farm, and non-farm) and to identify major consumption smoothing strategies. As a result, non-agricultural sectors are given due consideration, and differences in supply response between food deficit and food surplus households can be accounted for.

Finally, bioeconomic modeling is recommended for a thorough examination of the sustainability implications of production technologies. Bioeconomic models allow for the evaluation of both current and alternative (more sustainable) technologies, as well as their contribution to farmer welfare and agroecological sustainability. Trade-offs between the two objectives can be identified, as well as policy instruments to promote the adoption of sustainable practices.

Conclusions

Sustainability concerns in low-input agriculture, as practiced in particular in the poorer parts of the developing world, are primarily focused on the depletion of the natural resource base as a result of increased land pressure. We have approached sustainability in this manner in this paper, emphasizing a combination of selective external input use and improved farming practices. This requires farmers to become more integrated into the market economy and to sell a portion of their output in order to earn cash for input purchases. This strategy is dependent on the development of well-functioning markets and a transportation infrastructure. To identify and select sustainable and profitable farm practices, a thorough understanding of production processes and household choices is required. The crux of the issue is converting this detailed understanding into a set of general best farming practices and disseminating this knowledge to a large number of farmers. Training, education, and extension can all help to increase access to such knowledge. Farmer organizations, co-operatives, fairs, and markets all contribute significantly to the knowledge and information exchange in rural societies.

In high-input agriculture, as practiced in the majority of developed countries, sustainability concerns are quite different and are primarily focused on the negative externalities of agricultural production (e.g., pollution), the loss of genetic diversity and nature, and food safety and animal welfare standards. Not only are the issues at stake distinct, but so is the institutional framework within which they can be resolved. Markets, support services, mechanisms for exchanging knowledge and information, and legal systems are all relatively developed.

In this context, governments frequently seek to mitigate agricultural production's negative externalities through negotiation and legislation. Targets (sometimes voluntary, but more frequently imposed by law) are established to phase out undesirable production practices, such as the use of certain pesticides or methods of livestock raising. Establishing such targets typically entails considerable political wrangling, including lengthy debates over the scientific evidence advanced by governments in support of tighter restrictions. Once approved by parliament, enforcing such legislation can be challenging at times, given the large number of farmers still in existence. Not only governments, but increasingly consumers, can impose restrictions on agricultural production practices. Their tolerance level is frequently lower than the government's, and they can most effectively express their concerns through consumer organizations and market channels.

The ability to phase out harmful production practices is highly dependent on the availability of technological alternatives. Generally, governments in developing countries are unable to offer generous financial incentives, and a significant impediment to the adoption of more sustainable practices remains their economic viability. Returns on sustainable agriculture must be sufficiently attractive in comparison to income from off-farm employment, and sustainably produced products must eventually be competitive on the market. Even when cost-benefit analyses indicate a favorable outcome, farmers must carefully consider additional factors and risks. Given the high labor requirements of the majority of agroecological practices and existing constraints on factor substitution, both land and labor returns must increase concurrently. Thus, increasing reliance on purchased inputs may be a preferable mechanism for farmers' incomes to remain stable and food security prospects to improve. Additionally, at least three conditions must be met to ensure that SAI benefits both farm productivity and household income.

To begin, when public investment and services are made available to farmers in remote regions, the economic viability of more sustainable practices can be significantly enhanced. Without such efforts, low-input technologies are typically limited to medium-sized farmers who engage in minimal market exchange. Market development and cost reduction are the primary prerequisites for agricultural intensification, as they facilitate access to complementary inputs and provide incentives for investment. As a result, increasing poor farmers' access to physical infrastructure is a critical component of equitable and sustainable rural development.

Second, sustainable intensification necessitates increased access to (information about) factor and commodity markets in order to mitigate uncertainty and enable flexible responses to changing production and exchange conditions. Significant increases in agricultural productivity can only be achieved through the combination of internal farm household resources and selectively applied external inputs. When input efficiency and factor substitution are taken into account, agricultural yields are highly dependent on the ability to overcome critical input constraints. As a result, it is necessary to ensure the availability of complementary inputs and the availability of labor to ensure their timely application.

Third, the adoption and maintenance of sustainable production systems are critically dependent on policies that encourage farmers to invest in more integrated farming systems. Even though land and water conservation practices, improved tillage systems, and improved nutrient management all have the potential to increase productivity, poverty alleviation requires the availability of financial services, marketing outlets, and off-farm employment opportunities. While structural adjustment policies improved market prices in general, input costs remained high and delivery systems remained inefficient (Kuyvenhoven et al., 1999; Reardon et al., 1999). Access to inputs demonstrates a strong relationship between individual characteristics (most notably education) and community networks. As a result, investments in human and social capital can be especially beneficial for accelerating the adoption of sustainable practices and technologies.

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