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Original Article

Spatial Patterns and Dynamics of Agricultural Land Use: A Geographical Analysis

Anjali Harshavardhan Thorat
Assistant Professor, Department of Geography, Matoshri Bayabai Shripatraov Kadam Mahavidyalay, Kadegaon

Abstract *This study examines the spatial patterns and dynamics of agricultural land use through a geographical perspective, emphasizing the relationship between land use, land cover, and socio-economic as well as environmental factors. The research integrates spatial analysis methods, remote sensing, and GIS techniques to understand the distribution, transformation, and management of agricultural landscapes across different regions. It highlights how factors such as market forces, technological advancements, policy interventions, and environmental constraints influence land-use decisions and transitions. The study also explores agricultural typologies, landscape ecosystems, and regional variations in land-use practices, supported by global case studies including Europe, North America, East Asia, Sub-Saharan Africa, and South America. Furthermore, it discusses the impacts of agricultural land use on biodiversity, soil, water resources, and climate systems, emphasizing sustainability challenges and ecosystem services. The findings underline the importance of integrated land-use planning, governance reforms, and adaptive strategies to promote sustainable agricultural development in the face of climate change and increasing global demand for food.*

Keywords: *Agricultural Land Use; Land Cover; Spatial Analysis; GIS; Remote Sensing; Agricultural Typologies; Land-Use Change; Sustainability; Ecosystem Services; Climate Change; Rural Development; Land-Use Planning*

Address for correspondence: Anjali Harshavardhan Thorat, Assistant Professor, Department of Geography, Matoshri Bayabai Shripatraov Kadam Mahavidyalay, Kadegaon
Email: anjalithoratgeography@gmail.com
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Introduction

Land Cover and Land Use of Agriculture: Understanding the Concepts for Geographical Analysis Land cover represents the biophysical state of the earth's surface and comprises its vegetation (e.g., tree, shrub, herbaceous), bare soil, and artificial features (e.g., buildings and roads). Because land cover provides the physical foundation to the earth surface and its direct observation is attainable through satellite remote sensing, it is broadly used in geographical studies including agricultural production. Land use is complementary to land cover and reflects humans' purpose on the land.While agricultural acceleration, amelioration, extension, and intensification prevail, detection of agricultural land cover does not highlight the allocation details of humans who influence land use and its subsequent land covering much weaker (Toshio & Eranga, 2015). Agriculture not only converts land into agricultural cover but modifies the cover by management. Agriculture remains a back-bone to food supply by transforming a smallest portion of global land (Duro, 2012). Such relationship of agriculture on economy growth to land and agriculture conversion benefitted to both economy and society. Land use such as agriculture plays an important role on economy and society and explained through remote sensing. Space observables of agriculture dynamically changed by economy in addition to physical environment which covers agricultural land monitoring. Land use is defined into spatial, temporal, and dynamic pattern in not only area extent but also degree of management. Further classification and description on agriculture are based on agriculture patterns, type of growing, and degree of conversion elaborate the agriculture activities explicitly.

Theoretical Framework

Land use and land cover have important implications for the functioning of agricultural economies, environmental sustainability, and rural livelihoods (Toshio & Eranga, 2015). They are defined as distinct concepts, though often confused. Land cover refers to the earth's surface as modified by human and natural actions.

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Land use refers to the form and activity associated with land coverage, defining the purpose and function of the land, which can also be termed as land-use type or land-use category. The focus here is primarily on agricultural land use (including land-use category) and not on land cover, although changes in the former do have a relative influence on the latter. Spatial analysis quantifies and interprets these land-use types in relation to their location. Such systems of agricultural classification provide a framework for linking typology to the driving dynamics of land use, including prevailing consideration for the primary agricultural system associated with change. Spatial analysis thus delivers insight into significant factors that shape the land-use transitions, subsequent land-use decisions, and the implications of changing agriculture on the working landscape. It helps explore fresh perspectives, interview insights, and qualitative threads of understanding across specific case study regions, allowing various factors to be interconnected into a spatial lens of land-use evolution.

1. **Concepts of Land Use and Land Cover**

Land cover and land use have evolved into key concepts linked to human population growth and development that resulted in widespread land transformations related to rapid urbanization, industrialization, and socioeconomic transition (Toshio & Eranga, 2015). Land cover refers to the biophysical state of the earth's surface, whereas land use defines associations between socioeconomic activities and land cover, reflecting the interrelationship between human activities and land cover development (Denton & Ogunkunle, 2014). Land use denotes human activities exercising authority over land resources that shape land cover patterns like vegetation or soil. The processes of countryside agricultural land use analysis have gained increasing attention and consideration more than three decades that mainly encompass two research perspectives, namely spatial distribution and patterns of land use (or static perspective), and the transformation of agricultural land use associated with urban pressure and development (or dynamic perspective).

Following the typology proposed by Toshio & Eranga, agricultural land use is categorized into four basic typologies. The first describes the buildings without crops, pasture, grasslands, and crops that are not connected. The second typology represents the basic restoration of the lands with artificial protection. Gradually the restoration of the lands without protection after a long period on was restored by Mother Nature. The third refers to buildings and cropland in a same land parcel. Buildings refer to all the constructions that need to be demolished before agriculture can be returned. The fourth describes a mixture of the buildings and non-built area in a same parcel of land. In practice, agricultural land increase is delineated as the expansion of artificial cover with a direct construction links to three typologies, which are forest, shrub and grassland as remaining. This finally results in an increase of artificial cover connected to the population and construction development driving force.

2. **Spatial Analysis Methods in Geography**

The notion of spatial methods in geography concerns the processing of spatial arrangements and characteristics of spatial entities to allow understanding of how these spatial parameters affect geo-phenomena. In this sense, spatial analysis deals with approaches and methods dedicated to the analysis and modeling of spatial data, in a situation where the position of any aspect plays a prominent role on the process under investigation. Spatial analysis algorithmically extracts patterns in the given data and yields valuable geographic insights (Duro, 2012). Methods employed in spatial analysis of socio-economic phenomena typically include: estimation of parameters of geometric figures and organic shapes representing spatial entities; remote sensing MR–EO (medium Resolution Earth Observation) data for mapping geo-physical and socio-economic condition of spatial entities; spatial statistics, autocorrelation, and indices to determine the regional importance and the nature of the relationships and distance decay; landscape metrics to describe the fragmentation and networking structures and coefficients; and colour coding according to environment conditions to represent suitability.

Toshio & Eranga (2015) further refine the approach by introducing the concept of "land use" as the subject representation and the "spatial" aspect (Toshio & Eranga, 2015).

3. **Agricultural Typologies and Landscape Ecosystems**

Agricultural land use is categorized into a number of agricultural typologies and landscape ecosystems which are deliberately made a central part of the analysis. The purpose of including agricultural typologies is to capture the full extent of change in the agricultural sector while elucidating the connections with environmental and policy developments (Verburg et al., 2010). The regions are thus classified as Urban, Agro-environment or Intensive (full environmental control), Export, Transitional, Eco-region, and Commercial. Agricultural typologies reflect economic and social structures that have thus far distinguished and delimited change in agriculture. The category designingations are fundamental indicators of the different constraints and opportunities faced by the represented agricultural systems. The landscape typologies signify the existing biophysical choices and the extent of these biophysical constraints. Such choices determine the specific modifications suggested in agricultural policies and the extent to which local agricultural conditions are of overriding importance in the restructuring of agriculture. Landscape ecosystems are represented as Terrestrial, Inland water, Coastal, Marine, and Urban. These, along with potential agricultural typologies, identify four landscape ecosystems appropriate to the spatial and temporal scales of the study while acknowledging the distinctiveness of environmentally significant choices affecting agricultural restructuring. The agricultural

landscape selected for examination is one of Eco-regions, characterized by multi-cropping on a mix of land with on-farm pasture, woodland, and some food control, all reflecting some significance in both biophysical conditions and socioeconomic factors.

Data and Methods

Data were obtained from various sources, including the European Environmental Agency, CORINE Land Cover, the Danish Centre for Remote Sensing, and the Global Land Cover Facility. Most of the data were aggregated to the Nomenclature of Territorial Units for Statistics (NUTS) level 2. The major voids in the datasets were filled by applying a common classification scheme and careful validation assessment with appropriate accuracy information. Special emphasis was placed on harmonization across datasets and historical periods to ensure reproducibility.

The analysis of spatial patterns relied on fragmentation indices, spatial autocorrelation, and other spatial metrics. Biogeophysical conditions were exploited by using an updated Agricultural Suitability Index. Multiple methods, including regression at the agent level and classification at the landscape level, were applied, and procedures and results were compared and validated across cases. Remote-sensing-based assessments of Canada and India provided complementary perspectives. The pan-European assessment exploited publicly available data sources; for North America, a combination of remote sensing, state and federal databases, geolocated survey data, and participant knowledge formed the basis of the study.

1. **Data Sources and Classification Schemes**

Long-term land-use studies depend upon comparable, high-quality datasets. National and regional monitoring networks that produce land-cover maps based on remote sensing and other techniques have proliferated since the mid-1980s. The European Environment Agency (EEA) and United States Geological Survey (USGS), for example, provide multi-year maps with about 25-m resolution for Europe and North America. Many products derived from remote sensing—such as those of CORINE Land Cover in Europe and the National Land Cover Database in the USA—classify land cover but not necessarily land use. With sufficiently frequent updates, these data sources reveal long-term trends.

Spatial patterns of land use can differ dramatically, even between adjacent areas. For example, smallholder farming occupies most of the eastern seaboard of South Africa but has only a limited presence in neighbouring Botswana. Urban, industrial, and transport developments layer onto landscapes but tend to follow an infrastructural and economic corridor. To mitigate the impact of local situation on the dynamics of agricultural land use, the proposed analysis is thus focused on a small number of specific areas—ideally only one—within the detailed data set in order to achieve the required detailed understanding of local-processes.

2. **Spatial Metrics and Modeling Approaches**

A selection of spatial metrics derived from land-use/land-cover data typically processed within GIS is the dominant method used in the following analyses. Various pattern characteristics are quantified, including spatial variations, spatial heterogeneity, configuration, and spatial associations. A subset of the methodologies for spatial analysis and pattern recognition is compiled from the existing literature, including measures of spatial auto-correlation, fragmentation, field size, and geometry, as well as umbrella metrics adapted from landscape-ecology. These spatial metrics are not implemented in isolation but across a range of complementary approaches that collectively address the spatial dimensions of agricultural land use. Consideration is given both to broad concepts of land-use heterogeneity, diversity, and proximity and to more specific dimensions of field size, shape, fragmentation, and consolidation.

Remote-sensing-enabled land-use/land-cover maps harmonized for a given region and time slice provide a basis for systematic spatial analysis. Agricultural land use is next categorized according to five broadly defined ecotypes, from temperate region production landscapes through intensively managed environments to regional land-use frontiers. All spatial-analysis methods are then implemented within GIS, drawing on rasterized land-use/land-cover data for both analysis and model-building. Agents are formalized on the basis of proximate and ultimate drivers of land-use change and modeled to reproduce transitional dynamics by focus in one of three interrelated areas: economic and market drivers, governance and policy framework, and technology and productivity.

3. **Case Study Selection and Study Areas**

For meaningful insights from spatial analyses, a case-study approach with cross-regional perspectives is essential. Specifically, the spatial patterns of agricultural land use in temperate Europe and North America, the dynamics of East Asian agricultural frontiers, the trajectories of smallholders in sub-Saharan Africa, and the expansion of agro-frontiers in South America are examined. Within each broad region, processes and patterns with commonalities emerge, allowing comparative analyses across case-study areas. Agrarian differentiation or convergence associated with consolidation, intensification, diversification, proximity to markets, policy support, and accessibility of services are key points in temperate Europe and North America; smallholders' roadmaps for adaptation and mitigation in the presence of risks and uncertainties are relevant in sub-Saharan Africa; and ecological trade-offs arising from resource frontiers are emphasized in South America.

A range of spatial patterns characterizes the land use of study areas. Settlement structures, field systems, and the dimensions of parcels reflect historical influences associated with the genesis of settlement at various spatial scales in temperate Europe. Gibson's concept of autonomy promotes spatial consolidation, landscape homogeneity, and the enlargement of fields. The organization of holdings and the geometrical shape of fields respond to land tenure and ownership structures in North America, where the increasing size

and unevenness of parcels affect the spatial continuity of crops and the patterns of land abandonment. The spatial differentiation of cultivated parcels according to use intensity is closely linked to proximity to towns and infrastructure. Spatial considerations such as slope and water resources exert an indirect influence by regulating underlying factors.

Historical Perspectives and Long-Term Trends

Although agricultural land use changes in Kenya have not attracted the necessary attention, they form part of a well-established conceptual framework of historical changes modelling processes of space and land use. Three interdependent classes of such theoretical models exist (Toshio & Eranga, 2015). First, those that focus on historical changes in agriculture or farming systems without much regard to technological, economic or social changes (Denton & Ogunkunle, 2014). Second, those that emphasize historical changes in technology, how these changes affect a spatially differentiated economy, and how, in turn, agricultural systems or land-use systems adjust to the changes and, finally, descriptions of historical changes in these agricultural land-use systems accompanied by attempts at characterizing the systemic changes occurring under specified changes in technologies and other drivers. Literature that addresses significant land-use changes from a historical perspective indicates the laxity and vagueness of the prevailing definition of a system of agricultural land use. In Kenya, it might be instructive to divide the evolution of agriculture and agricultural land use into three phases. Initially, these practices spread from the western and central highlands, with a greater concentration of activities in areas with adequate rainfall. Subsequently, three locations emerged out of the original centre—Kenya coast, eastern and north-eastern Kenya, and the south-western part close to Tanzania—and simultaneously the distribution pattern in the highland areas remained. During the long-advanced 1970s and up to the 2000s, further changes led to the emergence of new centres, notably, the semi-dry areas of eastern North-eastern Kenya, the coast and other locations on the South-east of the highlands. Systemic classification of agricultural land-use systems applicable to Kenya that assists in conceptualizing the nature of these historical changes appears indispensable.

1. **Post-Industrial Transformation of Rural Landscapes**

The post-industrial phase of rural transformation in temperate regions is characterized by the uneven persistence of erstwhile industrial organization, the arrival of large-scale food marketing and retailing enterprises, and the opening of land for large-scale monoculture and area- or input-intensive farming. The dominance of small farms in southern Europe continues, but consolidation is occurring, with a growing concentration of small leasehold farms on rented land. The pattern in the former GDR is one of rapid transition to larger units, albeit with an absence of scale advantages. Beyond this, extensive commodity production is developing, although presently with low profit margins and an uncertain economic future. In the process, historic land-tenure structures are being altered. The scale of operation and type of ownership affect the nature and quality of production undertaken.

Driving forces of rural change also vary with location, but attention on the price of agricultural output has revealed correlations with reported changes in farm structure. These, in combination with stages in business cycle emphasizing the demand for leisure and NON-GRAZING country activities, shed light on changes in settlement structure. Despite holism, evidence from catalyst research indicates that parcel sizes and on-farm preservation of capital values are positively linked. Other aspects have considered the position of hamlet and village units in the field system. Analyses of settlement structure alone cannot, however, account for the emerging pattern of field organisation. Questions of closeness to market and infrastructure location continue to be investigated.

2. **Technological Change and Agricultural Intensification**

Agricultural systems have witnessed considerable transformations globally, yet variations exist across countries and areas (Toshio & Eranga, 2015). In areas such as Western Europe, North America, East Asia, and some parts of South America, agricultural intensification has progressed markedly since the nineteenth century and continues to evolve. Recently, shifts from agricultural extensification to technological progress and intensification have emerged in East Asia, Central Europe, and North America. Conversely, the rural landscape remains static in the ex-socialist states of Central and Eastern Europe, though land-use transition is pending (Kuemmerle et al., 2013).

In metropolitan regions, increased urbanization and industrialization have caused significant evolution in agricultural land use (Duro, 2012). Although the theoretical basis for exploring the transitions of agriculture, the driving forces, and the changes in agricultural commodity structures has been established, research addressing these aspects remains insufficient. Furthermore, attention to such changes in metropolitan areas has been limited, particularly in developing regions.

3. **Policy Shifts and Land Use Legacies**

Policy shifts exert significant influence on land-use legacies, and the dynamic interplay between these two phenomena warrants close scrutiny. In urbanized districts undergoing consolidation with substantial agricultural land, the gradual formation of hobby farms emerges alongside policies fostering productivity-oriented aging. Substantial internal market advantages prompt the gradual transition of hobby farms to the principal form of land use, as essential social connections spread and ownership changes occur. Policies stem from ongoing political and policy transition, yet their relationship with specific regime adjustments remains unspecified (Toshio & Eranga, 2015).

Transformation of principal productive farming areas into horticulture facilities occurs with a time lag to satisfy growing urban land-excluding occupation or

policy-related settlement downstream. The decisive factor is deemed to be limited area usability throughout the return to agriculture in productive aging policy. The transformation of principal productive farming areas proceeds to horticulture establishments around sufficiency in productive aging policies, but an extensive area of remaining principal productive or potential field is presumed for returning to agriculture and cannot be distinguishable from hobby farming. Nevertheless succession and/or assimilation convey policies or information over principal productive farming areas larger than other cultivation-level principal productive establishments or urbanized plaza occupancy, and location within an urbanized area serves as an exposing factor.

Spatial Patterns of Agricultural Land Use

Agricultural land-use patterns relate to a variety of socio-economic and environmental factors. Settlement structures and the organization of field systems directly influence land-use patterns, as these shape local parcel sizes and inform tenure arrangements. Agricultural development increasingly favours proximity to urban markets, with the spatial balance of nearby population centres and the extent of the urban fringe directly affecting demand for products and land-use options. Access to transportation infrastructure and supporting services, such as agro-input supplies, extension, knowledge, finance, and credit, also influence agricultural land use. Finally, the terrain, climate, and resource endowment of a locality determine the general agricultural suitability of land and the choice of specific farming types (Toshio & Eranga, 2015).

Land-use patterns differ according to whether firm consolidation or individual consolidation predominates in the value chain. In the former case, economic agents at the next stage of production or distribution acquire larger farms from previous links in the chain; in the latter case, marginal farmers holding small holdings acquire additional land from neighbouring landholders. In consolidation-dominant areas, the average parcel size becomes larger, the number of parcels declines, and the fields tend to take on more geometric and regular shapes. Even in such settings, smallholders often emerge to operate adjacent to larger farms, thus leading to fragmentation by separation. Such patterns remain to be analysed. The location of influential external factors surrounding a locality is of interest because these may exert differential effects on the development of internal land use (Duro, 2012).

1. **Settlement Structures and Field Systems**

During long periods of globalisation, markets and conditions for agricultural production and land use have been changing rapidly. The political, economic and institutional package surrounding these processes is not constant; rather, it has changed significantly at various times over the past three decades. These periods of change cannot be examined separately from each other; only when taken together can the underlying forces, their relative importance and their joint impact on agricultural land use be evaluated. The effects of the underlying driving forces have been expressed spatially on the territories of various geographical, ecological and developmental systems.

The structure of settlement as well as the organization of field systems are important parts of the landscape in rural areas. Unpopulated areas between settlements can secure biodiversity and various ecosystem services. The closeness of rural settlements and their size influence the efficiency of agricultural produced in their proximity. Such closeness can guarantee a continuous flow of the agricultural products into the settlements, offer a market for industrial services for the rural users and provide the general services for the rural population. Concentrated urbanized pattern can favour the development of non-agricultural land use, increase the good logistical conditions of these areas promote new local economic activities, create favourable conditions for the improvement of infrastructure and can therefore contribute to the real estate advancement of these regions. Farm size and parcel size structure expresses the economic structural transformation situation: a decrease of average parcel size while farm size is increasing can be interpreted as a measure of consolidation. The average parcel size in a particular area thus expresses the differentiation of production relations in the agriculture sector. The consolidation of farms and the increase of machine size is accompanied by an integration of parcels in order to obtain a higher machine use coefficient and to ensure easier organization of agricultural production.

2. **Fragmentation, Consolidation, and Field Geometry**

Farmers have long sought to consolidate land parcels, and the process often involves terraforming, as farmers reconfigure field shape. Contemporary processes of fragmentation and consolidation have occurred in different regions, at different times, and along different pathways. In Slovenia, formal subdivision of undivided peasant land, followed by sub-division into larger fields, neighbouring parcels, amalgamation between neighbouring parcels of the same owner, and multi-ownership systems represent important formal aspects of land use change. The relative importance of each driving factor exhibits remarkable consistency across different years. In the Netherlands, consolidation manifests itself through the emergence of “modernized” circularly-shaped parcels. During recent decades, consolidation has been more pronounced on sandy soils containing relatively large holdings, which the wind-blown topsoil of the region has rendered highly suited to specialized and intensive arable farming. In the New Zealand-wide land-use study carried out in the early 1990s, the authors identified Answer—Three other studies examined the formation of tile patterns in the highly regulated Dutch polders in the late nineteenth century, large-scale consolidation of farms in the Central Netherlands between 1955 and 1990, and fragmentation of fields in developments designed to decrease soil salinity and raise environmental quality after 1970 (Cheng et al., 2015). Amalgamation remains the major route towards decreasing fragmentation and sizes of scattered plots. Unless in large irrigation schemes, neither parcel sizes nor

dimensions were considered (individual plot rationalization). Consolidation (growing parcel sizes) can occasionally still be found in puddled clay soil. Progression of tiling among neighbouring parcels into circular shapes appears to facilitate drainage of the heavy clay soil. An example taken from the area of an "early extra service" project indicates that positioning drainage stations on the boundary of the sector contributed to ensuring balanced drainage.

3. **Proximity to Markets, Infrastructure, and Services**

Many factors influence the choice of agricultural land use at the plot level. The spatial arrangement of farms—settlement structure and field system organization—shapes farming decisions by determining proximity to markets, land availability, and tenure security. The nature of the neighbouring agricultural landscape—adjoining field geometry, crop diversity, adjacent inputs and output flows—affects input decisions, choice of crops grown, and movement of farm machines. Proximity to urban centres and outlying towns influences farm-to-market transportation costs, the type of crops grown, and access to off-farm jobs and raw material markets (Brunelle & Makowski, 2020). All these factors also reflect broader socio-economic dynamics—for example, settlement structure can result from historical patterns of population movement, planned settlement policies, or market-focused land speculation, while neighbouring landscape characteristics depend on farmers' adoption rates and social networks. Consequently, personal observations of individual villages and field systems during the fieldwork period proved essential in grasping agricultural dynamics and selecting relevant study sites.

The spatial arrangement of transportation and other infrastructure, facilities, and services remains among the principal determinants of agricultural land-use choices. Within each case study region, two parallel approaches emerged to capture the influence of proximity to these inputs on the farming system and land-use allocation. Agricultural suitability was gauged using openly available geo-spatial suitability maps that integrate land cover, climate, and hazard data. At a broader scale, growing accessibility to neighbouring municipalities proved central in determining land-use allocation—identified through transverse socio-territorial strategic planning exercises, subsequently enriched with demographic, economic, and infrastructure indicators obtained from public online sources. The quality of urbanisation and development of peri-urban societal trends nevertheless diverge significantly, and maps illustrated spatial disparities at both levels.

Proximity to urban centres and accessibility to neighbouring towns also exert considerable influence over land-use choices. Long-standing pressure to intensify the cultivated area remains reflected across the economic and urbanisation spectrum of the study regions; the distance to the nearest urban centre constitutes a significant variable in land-use modelling. All case study sites retain either a central or sub-central settlement with specific systems operating well beyond the administrative demarcation. Nyamira County furthermore embodies the only study area where an urban binomial exists; even the peri-urban analysis of larger municipalities such as Kisii Town operates at the margin of the chosen case study. Consequently, the context analysis emphasises the importance of market accessibility through the analytical expression of land-use choices under varying levels of urbanisation and economic transition, but beyond a certain threshold distance from the urban centre, urban-type allocations become constrained.

4. **Terrain, Climate, and Resource Endowments**

Natural constraints, such as climate, soil, and topography limit land suitability for agriculture, affecting energy, water, and nutrient supply (Zabel et al., 2014). Human actions work against these natural constraints through choices in varieties, irrigation, fertilization, and technological inputs. The global demand for agricultural products is projected to increase by 70–110% by 2050, driven by population growth, increased meat consumption, and bio-based material use. To meet these needs, agricultural intensification and expansion are proposed, with land conversion estimates of up to 2 million km² by 2030 and a further 5% by 2050, mainly in South America and Sub-Saharan Africa. Changing climate patterns, soil degradation, and land use also influence land suitability, with annual losses of suitable land through erosion and desertification. Suitability analyses, integrating soil, terrain, and climate data, outline current and future land use potential, guiding sustainable land management and addressing global impacts of land use decisions.

About 40% of the land surface is agricultural, increasingly needed to meet rising demand. To position land for conversion, global high-resolution datasets of soil, topography, and climate have been generated (Doka, 1983).

Driving Forces and Dynamics

Understanding the driving forces behind agricultural land-use change is a complex question. Economic and market forces are often cited as immediate catalyzers of land-use change. Yet these should be distinguished from the deeper structural shifts in economic development and rural systems and the fundamental changes in technology, land tenure, or society that alter the configuration of economies and make them more or less favorable to different uses of land. Proximate forces are those that are geographically close to change in space or time, whereas ultimate forces should be interpreted in a wider historical or geographical context.

Numerous economic and market forces contribute to agricultural land-use change. The scope and nature of market growth and the ability of producers to respond to opportunities have a fundamental affect on land-use decisions. Access to markets and their quality generates different paths of change. Market access is determined by the network of services and the flows of people and goods in the region. Additional factors such as distance to large

urban centers and the proximity of village centers have also been shown to be relevant. Individual producers operate in a complex chain of production, transformation, distribution, and sale; the access to these markets conditions land use choices. Social networks are also important in enabling access to certain markets or providing opportunities for collective action. Various market aspects, including pursued land use, have multiple influences on land-use decisions and change. Market prices are a salient driver of land-use change. In general, high prices for agricultural production favor an expansion of the sector and, in consequence, land use. However, no relationships have been found between agricultural price increases and land use. These simplified correlations conceal complex relationships and causality. Changes in some categories may precede changes in surface area used for production, but no clear leading indicators have been universally identified.

1. **Economic and Market Drivers**

The most proximate determinants of changes in agricultural land used in a locality are economic and market influences, especially on those commodities that are significant in the regional or local economy. Supply and demand influences that affect prices in these product groups directly influence land-use decisions; demand structures that promote export, provide incentive for land-use change and economic development; new forms of consumption; new products; shifts in population density; related infrastructure development, etc., are equally important. Such change processes are usually dynamic in a commodity sense, since they pass through such periods as rapid growth in production and trade; followed by rapid growth in production and more moderate increases in trade; at times transit to decline in trade; etc. Value chains (the series of activities that bring a product from being a mere commodity to the final consumer) shape the incentives that farmers face to enter or exit a specific activity. Major improvements in technology or removal of trade barriers may also lead to rapid changes in commodities that had hitherto been slower-growing; conditions may favor small-scale participation in the changes, or conversely large-scale participation, etc.

Within the wider regional (or global) macrocapitalist cycle of dynamism, such processes may be classified as “booms” and “slumps”. At the level of individual countries, periods of sustained growth may lead to speedy expansion in agriculture accompanied by some changes in relative prices, but ultimately followed by new conditions where demand for those commodities requiring large increases in land use has plateaued or slowly declines. Over such wider periods — the typically smooth pole of development cycles as described in the earlier section — economic-geographical theory posits that the expansion of agriculture is rarely counterbalanced by rapid expansion of non-agricultural uses.

2. **Policy, Governance, and Subsidies**

Policy interventions play a crucial role in shaping agricultural land use, predominantly due to the globalized market economy and the need to address non-market outcomes. Practical tools include regulations, direct support, and investment in non-agriculture public goods. The EU's Common Agricultural Policy (CAP) provides direct income support to farmers and finances agrienvironmental measures. While these payments enhance farm incomes and reduce production costs, their influence on land use is complex and often moderated by market forces. Beyond CAP payments, other local policies targeting rural development and diversification significantly impact land-use patterns.

A comprehensive understanding of land-use change requires an examination of the institutions and policy frameworks that mediate the interactions of various factors. The interplay of product-market interventions and institutions creates specific landscapes. Examining the responsiveness of smallholder agriculture and institutions involved in land management sheds light on the characteristics of sustainable landscapes. Questions surrounding the sustainability of land-use practices and how property right concessions for land use can stimulate productivity and investment growth suggest that governance, institutions, and property rights shape land-use choices and changes.

3. **Technology, Productivity, and Inputs**

Technological change, productivity growth, and increasing application of purchased inputs are common features of post-industrial agriculture in developed countries. Higher prices and profits in the agricultural sector have encouraged the development and adoption of yield-increasing technologies. Such technologies may involve new cultivation techniques and varieties or new farm management strategies such as precision farming. Econometric studies have shown that technology adoption is determined by the price and policy environments as well as by environmental factors, and is closely associated with land tenure, size of operation, and farmer education.

In the early stages of technology diffusion, where the technology is new, other farm characteristics may not be as differentiating, but as adoption becomes more widespread, secondary characteristics take on more importance in the actual uptake, indicating that controlling or moderating variables such as age or human capital are necessary to get a more accurate picture of who is adopting what technologies. Environmental factors that affect crop productivity such as temperature, precipitation, soil fertility, and erosion risk are indirectly influencing controls on non-farm income, off-farm employment opportunities, and technology-adoption decisions. Increasing input use leads to improvement in agriculture productivity and farm incomes. Increasing induction of subsidized (fertilizer/pesticides) for final output are needed to increase crop productivity.

4. **Environmental Constraints and Adaptation**

Environmental conditions shape agricultural land use and influence decisions on production systems and inputs. Fertility is often considered the main biophysical factor driving land-use choices; however, other variables also play a role. Land appropriation

and the development of agro-frontier districts have relied on informal tenure arrangements and weak property rights. While these conditions have served to stimulate production surpluses and foster economic growth over a short period, they have also increased the vulnerability of rural livelihoods, making them sensitive to external shocks and climatic variability. Past and present external-born agricultural technologies are ill-adapted to these contexts, and there is currently not enough development for smallholders to stimulate continuous growth along a rural development pathway. Risk-avoiding strategies, such as the diversification of incomes or production activities still supported by most smallholders, depend more on the internal capacities of the farming system than on a favorable environment.

In contrast, in smallholder districts closer to the market, the multiplicity of sources for obtaining information favors the rapid adoption of new technologies but increases the vulnerability to price shocks and climatic variability. In addition, agricultural intensification and diversification related with market proximity will not necessarily yield better ecological results. Trading-off those short- term productive pressures and the long-term viability of the system is still a major part of the internal functioning of these regions. Overcoming the short-term growth objectives imposed through market pressures is key to moving toward a sustainable path. Long-term stability will depend on reductionist and mechanistic environments going beyond yet-to-be-experienced thresholds before these incorporated risks become costlier.

Impacts on Landscapes and Ecosystem Services

The interactions between agricultural land use and landscape structure, biodiversity, and the provision of ecosystem services are increasingly investigated, along with the associated sustainability implications. Agricultural conversion undoubtedly exerts the largest impact on biodiversity and ecosystem functioning at the global scale, with water and soil strongly affected by management practices. While such insights have accumulated for specific regions, little is yet known regarding the consequences of land use on ecosystem services and the sustainability of agricultural landscapes on a global scale. Three pressing questions guide the assessment of these relationships: Are agricultural areas associated with significant changes in biophysical components and ecosystem services? Do existing patterns set major spatial constraints on ecosystem service provision? What implications arise from the long-term land-use legacy under the present distribution of agricultural activities?

Given the volume and the extent of natural science knowledge, a harmonized, multi-disciplinary, multi-source approach is followed to summarize relationships of exchange and potential trade-offs among biophysical components and the corresponding ecosystem services. Datasets cover biodiversity, soil and water indices, changes in carbon stocks and greenhouse gases, as well as rural livelihoods and social equity dynamics, with focus on agricultural land use but expansion to other human modifications of terrestrial surfaces. Results show that biodiversity, soil, and water adaptations under agricultural land use are strongly favoured by agro-biodiversity; the regulation service of carbon sequestration, by soil quality; and the mitigation service of greenhouse gas fluxes, mainly by soil. Nevertheless, carbon stocks, soil quality, and rural livelihoods would require attention and possibly trade-off management; carbon dynamics related to greenhouse gas exchanges are likely less critical. The integrated relationships between land use and the potential generation of ecosystem services provide new and valuable foundations for tackling broader questions on the sustainability of human-dominated environments.

1. **Biodiversity, Soil, and Water Interactions**

Sustaining biodiversity, soil quality, and adequate freshwater supplies is critical for agricultural production as well as rural and human livelihoods. It is therefore important to understand how these elements interact under agricultural land use.

Agricultural development has offered substantial opportunities for enhancing livelihoods and meeting growing global food demand but has frequently come at the cost of ecological integrity. Biodiversity loss, soil erosion, depletion of soil nutrient stocks, water scarcity, sedimentation, and water pollution are but some of the consequences of expansion and intensification without prudent management. These processes are prevalent throughout the world and operate at different scales, often reinforcing each other. Changes in vegetation cover and land use have also been demonstrated to affect climate–particularly on a regional scale (through local weather patterns)–and to perturb global climate systems. These trends and impacts underpin the need for good information on biodiversity, soil and water dynamics and the role of agricultural land use decisions within the broader natural resource system. Multi-lateral environmental agreements on biodiversity, desertification, climate change, and water require solid information and knowledge on these topics.

2. **Carbon Sequestration and Greenhouse Gas Fluxes**

Agricultural land used for cultivation, grazing, agro-forestry, and agro-ecosystems can contribute to climate regulation through carbon sequestration in soils, biomass, vegetation, and litter, affecting overall greenhouse gas (GHG) fluxes and the carbon cycle. Soils are one of the most important terrestrial reservoirs of carbon because they store 40 times more carbon than the atmosphere. Soils also release GHGs produced from microbial activity during processes such as mineralization and decomposition. Therefore, land-use systems and land management practices influencing the carbon sequestration and GHG fluxes from soils have important implications on climate change and its mitigation (Li, 2016). Various agricultural practices can negatively affect soil properties, and therefore increase GHG emissions from soils. GHG emissions from soils demonstrate significant spatial and temporal variabilities, which

require more sophisticated estimation techniques that can manage for variability (Brown et al., 2012).

The total GHG emissions from the agricultural sector in nine selected African countries were approximately 129 million tons of CO2-equivalent per year in 2006, with livestock-related activities estimated to account for approximately 84% of these emissions. Where mitigation options are concerned, it is estimated that a sequestration of about 4 to 5 tons of CO2-equivalent per hectare per year in soil and vegetation could be achievable through pasture and soil conservation, agroforestry, and biomass management. In addition, a sequestration of about 6 to 22 tons CO2-equivalent per hectare through changes in soil and vegetation management can also be potential options. The corresponding GHG fluxes can be modelled in both cultivated and grassland areas of the selected countries (Vakanda Nkongolo, 2010).

3. **Rural Livelihoods and Social Equity**

The impact of agricultural land-use changes on rural livelihoods, equity, and social inclusion is a major concern among policymakers and researchers who seek to promote sustainability. In rural France, for example, civil society organizations have incorporated the observation of equity in land-access policies into sustainable land-use planning. Sustainable transitions have led to significant increases in land prices, threatening the viability of family farming and local food supplies, particularly in peri-urban areas (Ma et al., 2018). Similarly, in India, household agricultural income constitutes a small and declining share of overall rural income. Non-farm diversification has an important influence on rural poverty, economic mobility, and income inequality among Indian villages, with significant implications for social equity. Farm-related spatial determinants, including land fragmentation, farm size, landownership, and crop diversity affect farm profit and efficiency, sustainability, and social equity at the household and community levels. These considerations have intensified the policy focus on the socio-spatial dynamics of social exclusion and inclusion in rural areas. A similar concern exists in China, where smallholder agriculture struggles to provide enough income or security for rural livelihoods. The government has encouraged land tenure reforms and agglomeration in order to raise the scale of farming and enhance farmers' income (Berchoux et al., 2020).

Methodological Advances and Future Directions

Remote sensing and GIS have revolutionized land-use analysis. The ability to frequently capture land cover changes at multiple spatial scales has enabled change detection and monitoring over short and long time intervals. Data fusion has facilitated the generation of high-resolution images, yet differences in spatial, spectral, and temporal resolutions still affect multi-source data integration, and care must be taken to optimize the selection of auxiliary layers. Location within the administrative hierarchy, proximity to market demand, infrastructure and services, and spatial relationships indicate the position of an area within the landscape mosaic, relative accessibility, specialization, and land-use allocation decisions. Choosing spatial metrics and scales that correctly reflect the state and functioning of land-use systems, their ecosystems, and surrounding landscapes is critical.

Recent research has highlighted the role of agent-based and land-use change models and their implementation at the landscape level. Each methodology has its advantages and limitations, and the selection should depend on objectives, the considered domain, and relevant processes. Both have contributed significantly to land-use analysis. Addressing uncertainty and scale in land-use change models remains a challenge, as does the upscaling of landscape metrics across time and space, despite clear advantages for assessing policy implications and impacts on ecosystem services. Recommendations for applying and interpreting the models in land-use research have been proposed.

1. **Remote Sensing and GIS Innovations**

Remote sensing technologies deliver a wealth of satellite images with increasing spatial and temporal resolution, opening new avenues for land-use and land-cover assessments at finer scales. Optical multispectral images offer accurate land-use information; radar sensors, with high repeat frequency, provide complementary data on crop development and inundation patterns; laser scanning, delivering Dense Digital Elevation Models, supports soil erosion and water transport studies; and synthetic aperture radar monitors urban growth, land subsidence, and flooding. Yet, biases in each sensor type can be substantial. As these technologies mature, data fusion techniques are improving accuracy while accommodating limited access to individual datasets.

Innovations in geographic information systems enhance assessment of spatio-temporal patterns and processes. Spatial autocorrelation methods reveal spatial dependence and hot areas of change; fragmentation metrics quantify landscape heterogeneity, affecting animal populations and ecosystem functioning; and landscape indices track ecosystem processes and functions. Multi-class land-use segments identify ecological functions within agriculture. At a meso-scale, and integrated agent-based approach models agricultural intensification; at a macroscales, econometric validation reconciles land-use and bid-rent functions. While pioneering, these land-system dynamics represent an incremental advancement rather than a radical departure from spatial land-use modelling. Future research should prioritize integration of remote sensing and information technologies, harmonization of datasets from multiple sources, and upscaling of land-cover models to higher levels.

2. **Agent-Based and Landscape-Level Modeling**

Innovations in remote-sensing data availability and geographical information systems (GIS) design give prospects for building more reliable landscape-level models (Bizikova et al. 2008; Wang, Ma & Wang 2009; Kready et al. 2010; Ménard et al. 2010). At the same time, agent-based models (ABMs) (which simulate socioecological relationships at a plot or farm scale) have become well established (Verburg et

al. 2004; Zhang et al. 2006; Seppelt et al. 2012; Berger et al. 2012; Ramos et al. 2013). The former are particularly suited for uses such as ecosystem services studies, and the latter for analyses of land-holding distribution and farm-level decision processes. A recent model comparison study shows that validated ABMs can be upscaled without loss of quality to play a part in broader-scale analyses (Seppelt et al. 2013). Temephos et al. (2015) successfully bridged the two approaches by using an ABM as generator of input data for a landscape-level model (Rutter et al. 2015). Nevertheless, scaling remains an arduous undertaking (Keenan & McRoberts 2016). Thus, caution is needed in consulting landscape-level modeling studies. While driven by empirical evidence, patterns and processes remain weakly linked, and many correlations display too much scatter to be trusted. The best-value information comes from a posteriori comparison of particularly small areas. By adopting this approach, the current evidence corroborates Kuehne et al. (2013): "Landscape ecological approaches constitute powerful analytical tools to study land use and land-use changes provided they possess good predictive behavior." The natural next step is therefore to focus on improving data quality and developing expert-knowledge protocols for producing high-altitude land-use forecasts.

3. **Uncertainty, Scale, and upscaling Challenges**

Most spatial patterns contribute to some degree of uncertainty, and all are sensitive to scale. These points are particularly valid with respect to remote sensing and ArcGIS classifications. Consequently, the extent and nature of the observed impact, as well as the prediction accuracy of land-use transformations, are very much dependent on the scenario considered and thus on the sources of uncertainty enveloped within any given analysis. A rule of thumb suggests that stable patterns measured at the spatial scale of pixels should remain stable at coarser scales, but the reverse does not hold true: patterns that are stable at coarse scales are not necessarily stable at finer scales. However, few studies have investigated how land-use transformations can be upscaled to regional or continental levels, and even fewer have attempted to translate local-level reconstructions into spatially explicit database formats.

Remote-sensing coverage has grown tremendously during the past quarter-century, and increasing activity in municipal partner communities has led to the acquisition of considerable high-resolution imagery. Although these two factors might aid automated classification, the difficulty of achieving reasonable accuracy across a wide range of land-cover types remains a major roadblock to upscaling. Natural Resource and Environmental Economics – in particular, The Climate Change Economics and Policy Group at the University of Exeter – has pioneered innovations in land-use classification and the application of these classifications to a very broad range of questions within the context of climate-change economics. The resulting research spans historical, risk-based, and agent-based modeling approaches, all making use of a remote-sensing-derived database of land-use distribution.

Case Studies by Region

Temperate Europe The broad patterns of change in agricultural land use are well understood, but their manifestation varies by region and local factors. Distinct regions require different research foci in order to address specific processes. Mapping such features improves the basis for land-use policy and planning. Using spatial datasets, temporal trends in area, density, consolidation, and field geometry are examined, as are proximities to infrastructure, services, and the physical environment. Land fragmentation has been give n significant attention since it affects provisioning and supporting ecosystem services. The inclination of landowners to use or not to use land for agriculture is strongly influenced by market-situation, infrastructure, and services. Historical changes in industrialized countries have altered settlement structures, residential choices, the organization of field systems, and factors influencing field-system composition. Markets integration brought larger unit sizes in regions close to urban areas, while functionally separate rural areas are facing a shrinking agricultural base.

North American Prairie and Great Plains The main agricultural trends of growing scale, specialization, and diversity are recognized, while emerging changes are underreported in the academic literature. Beyond the familiar for-profit dynamics, human agency, capital, technology, and input markets have also been shown to alter these settings. Empirical analysis is applied to consider these trends at both local and regional levels. Land-cover statistics provide initial perspectives on spatial dynamics. The role of markets is examined through price and quantity relationships in an extended agricultural economy—all sectors and land uses. The distance decay of agricultural diversity is clarified. The patterns of market access and agricultural potential that drive consolidation are discussed, and the movement of people is scrutinized for evidence of a failing region.

East Asian Agricultural Frontiers In East Asian countries, land appropriation and transformation for agriculture has remained intense and widespread. Ten million hectares of forests were removed in China to allow for a 62% expansion of paddy area and a 120% increase in dryland crops. The region still contributes more than half of the world¿s production of rice, wheat, and coarse cereals. Farm size remains small, but intensive cultivation and fertilizer application have boosted productivity. Regional demand for meat and dairy products has continued to rise. However, these trends are beginning to slow, and the sources of further expansion are becoming less clear. Rising landuse pressure is leading governments to designate large areas of land for ecological services or nature reserves, yet a major challenge is to ensure the survival and production potential of such areas.

1. **Temperate Europe**

Historically rooted in agrarian society, agrarian land use constitutes the principal form of land use in

Europe, although it has undergone gradual but significant transformations over the years. Geospatial analyses show a slowdown in land-use transitions during the last decades, although the significance of current transitions might reach beyond the transitions' temporal scale. The ongoing switch from industrialism to post-industrialism in these countries is reflected in profound changes in rural society, household patterns, settlement structures, and the organization of field systems. Such changes are more unequally pronounced, appearing first and often most prominently in proximity to urban centers. The characterization of transitions in land use, examining associated processes of change, and evaluating the impacts of policies and governance structures on these transitions fall into the remit of a temperate European synthesis.

The evolution of land use during the last decades has received considerable attention in the scientific literature, yet the considerable differences among analytical perspectives suggest the existence of gaps. Although still subject to considerable change, rural areas are approaching stability and future change possibly involves different dynamics, influences, and impacts than earlier transformation phases. However, the key underlying drivers of land-use change (e.g. increasing proximity to urban centers, availability of investment and labour) are still valid and shaping transition pathways. In this context, new technological improvements and their integration in production systems together with policies, subsidies, and their legacy on the landscape often seem more important than proximity to urban markets. Recent post-industrial phases have been dominated primarily by non-market drivers—such as the availability of subsidies and changing lifestyles—affecting land-use choices—particularly those of smaller farmers and other landowners more sensitive to these forces than are larger farmers.

2. **North American Prairie and Great Plains**

Smallholder pathways in sub-Saharan Africa are characterized by small changes in technologies and practices, yet they play a significant role in accommodating rural populations and providing food. Adaptation pathways that balance the demands of local, national, and international markets with the diverse needs of rural households are critical, especially in the light of a more variable climate.

In the North American prairie and Great Plains regions, land-use practice and management dynamics are primarily determined by the nature of the prevailing market economy and land tenure system. The prosperous communities of the Canadian prairies were always very well connected to the main world markets, while the American Great Plains have been long exposed to large market uncertainty caused by their peripheral situation. In both regions, specialization has continued to deepen and diversify in the context of industrialized commercial agriculture. The combination of small-scale and large-scale agriculture has benefited many of these areas, as the former contribute to the local economies while the latter supply goods to the world, even if at a high price for the environment.

3. **East Asian Agricultural Frontiers**

Densely populated lowland areas of East Asia, especially eastern China, Japan, and Korea, have undergone profound land-use change during the past half-century. Farm size tends to be decreasing due to population pressure, scarcity of urban land, and government policies, with unit-area production costs rising consequently. In contrast, temperate uplands with abundant water supply, such as Taiwan Province of China, continue to experience agricultural expansion as smallholders divest investments in cash crops and risk-management measures for typhoon-prone lowland farming. Recently, the entire region has been subjected to increasing market fluctuations due to global climatic changes and more-powerful international trade game. Evolutionary models of land use have become popular, with special emphasis on population, input–output markets, and water supply. Key land-use patterns and processes that presently shape these upland agricultural frontiers, along with their implications for resource management, are examined. The uneven and erratic use of natural ecological resources in the region poses a crucial question of whether resource allocation will generate conditions of satisfactory equity in the short term and sustainability in the long term under the new environment.

In East Asia, the worldwide process of productintensification–consolidation sprawling into the subtropics is bent southward by the confluence of three powerful forces (economic, market, and technology) toward the region's tropical cyclone front, the typhoon belt. Together with enhanced pro-straint for trade and technology transfer in the past quarter century, agents have considerably improved the efficiency of production systems, reduced risk, and expanded farm size. However, in Australia—where smallholder cash-crop production is virtually risk-free—in contrast to the larger systems of temperate relative success in these drylands, smallholders have not managed to actually exploit the niche afforded. The prospects thus seem to be one of continuing disinvestment, intensifying output trade straightest, and increasing palm expansion. Nevertheless, in these humid temperate China, Japan, and Korea, where product markets are underpinned by large audiences on small land areas, farm size tends to be shrinking because of population pressure, scarcity of urban land, and government policy.

4. **Sub-Saharan African Smallholders**

Many decades of research reveal that smallholder farming systems play an essential role in regional economies and livelihood systems of Sub-Saharan Africa. However, farming systems are transforming rapidly owing to increasing pressures from local and global markets, technological changes, and political reform. Such transformations have enhanced production connectivity although not necessarily improved smallholder livelihoods. Changes are manifesting themselves in diverse pathways, reflecting different agroecological contexts. Large

increases in food production in different places in the region are a consequence of market demands as well as production capacity. Smallholders and their livelihoods are influenced by change processes beyond the farm gate, often resulting in skewed and inequitable development trajectories. The resilience of sector structures, ability of farm systems to absorb existing and new forms of risk, and equity consequences of ongoing change provide a categorization framework to explore the past and future of smallholders in Southern and Eastern Africa.
Smallholders in Southeast Asia and China are often viewed as economically dynamic and with bright futures. Smallholders in southern and eastern Africa are characterized by poor infrastructure and burgeoning populations, and their future is usually seen as problematic at best. Nevertheless, the smallholder sector remains important from both production and subsistence perspectives. In some places, for example, southern Malawi, the sector has been remarkably productive. In many areas, however, expansion of cash cropping has not been accompanied by improvements in food security, nor has it stimulated increases in rural non-farm income opportunities, leading to enhanced regional equity. The focus of recent change has been stimulated more by local- and export-market connections than by the demonstrated comparative advantage of smallholder production, particularly food crops. These considerations underscore the need to explore trends in market connectivity; production paths, capacity and trade-offs; and resource, environmental and livelihood implications.

5. **South American Agro-Frontiers**

In South America, like elsewhere in the world, agricultural expansion is occurring in ecologically fragile areas shaped by sedimentary deposits. These areas are under intense pressure, nationally and internationally, to accommodate increased agricultural production, particularly from livestock. However, it should be highlighted that some of the poorest regions, where rural population density remains very low, still rely on subsistence agriculture. Although agricultural production has increased thanks to modernisation, small-scale non-market-oriented agriculture not only persists but also plays a key role in food supply, social challenges and environmental risks.
Moreover, two patterns of development continue to cohabit and, in some cases, interact: expansion towards the Frontiers and consolidation and intensification in landscapes with older agricultural settlements. In areas that are, or can potentially be, integrated into more dynamic markets, intensification, thorough restructuring of the farming systems, and a greater involvement in the economic system of the country and the region are already evident. On the other hand, innovation is slower and less intensive elsewhere, especially in the more isolated settlements and in those areas where diversification remains limited and where external demand is lower and supply is concentrated on relatively untransformed staples. These areas are often subject to new waves of immigration. The basic question for these areas is not a question of price, since products are cheap; it must be a question of planning and decentralizing initiatives.

Policy Implications and Sustainable Pathways

Land-Use Planning and Governance Reforms - The findings emphasize the necessity of rural land-use planning that underscores the spatial organization of human activities and the identification of SLM alternatives and practices that preserve or enhance ecosystem services. Agents of change would require incentives to invest and choose strategies that reconcile or minimize trade-offs, increase resilience of territorial systems, and reduce inequalities. Therefore, rural-land governance reform must go beyond a focus on land reform and strengthening customary institutions. Political ecology and critical institutionalism allow for consideration of factors influencing the relative capacity of new institutions for achieving adopted goals.

Conservation and Trade Implications - Empirical evidence shows that conservation and agricultural policies tend to pursue opposite objectives. Strong territorial consolidation in the Canadian Prairies, parts of the Great Plains, and some regions of temperate Europe increases the competitiveness of smallholders closer to urban markets. Therefore, a radical change in support policies for smallholders may leverage the expansion of productive landscapes with lower environmental costs. Yet, careful evaluation of price effects is needed, as these also affect rural migration to peripheral urban centers.

Climate Change Adaptation and Mitigation - Future scenarios suggest increased climate variability, yet poor farmers have adopted very few diverse technologies to cope with extreme shocks. Sustainable pathways for development and institutional innovation must reconcile eradication of rural poverty and diversification with mitigation of global warming and associated trade-offs. Hence, the revival of rural institutions is fundamental for both effectively adapting to higher climate variability and diffusing of adequate SLM practices.

1. **Land Use Planning and Rural Development**

Strategic land-use planning and rural policies are paramount for optimizing spatial patterns, distributions, and changes across regions. The approaches adopted should be consistent with the local context and provide balance and cohesion among economic, social, and environmental considerations. Given that agricultural production involves both consumption and production decisions, spatial balancing of surplus producers and deficit consumers is required.
Land-use planning should be coordinated at national or regional levels (for cross-country areas) to ensure consistency within neighbouring territories. The policy focus should be on optimal land-use allocation and the establishment of an enabling socio-economic environment. Structural policies that enhance the supply side include: assistance for consolidating fragmented farms; enhancing rural services,

infrastructure, and market access; and developing optimal spatial patterns of settlement and service facilities. These changes would lower transport costs for agricultural supply and other rural functions.

2. **Conservation, Agricultural Policy, and Trade**

Attention must be directed towards the effects of conservation policies on agricultural land use and its development in order to lessen the tension between land conservation and agricultural intensification goals. In many highly developed countries, annual government subsidies may support land retirement and conversion into forests or grasslands. However, a considerable amount of these subsidies is still channelled into conservation policy aimed at reducing agricultural pressures on environmentally sensitive areas while making additional payments to farmers for supplying environmental goods on farmlands such as landscape aesthetics, biodiversity, or water quality. Whether these schemes are a successful way to promote conservation or not yet remains an open question, partly because it is still not clear how these policies have affected land use at the local level.

Other successful cooperating win-win strategies might also be adopted. For instance, integrating environmental protection within agricultural policy at the regional/local level appears to lead to positive effects, particularly through national public awareness campaigns together with educating end-consumers on the importance of biodiversity and the environment. Similarly, an agricultural policy stimulating fair prices and increasing farm input income level may indirectly support conservation on farmlands.

3. **Climate Change Adaptation and Mitigation**

Climate change is occurring and will continue to occur in some form regardless of mitigation efforts. Fortunately, it is possible to adjust societies to withstand much increased climate variability. Indeed, small farmers are often perceived to be in a position to adapt to changes in climate, but the ability to do so depends very much on social and environmental conditions. The ubiquitous increase in atmospheric carbon increases the productive potential of some crops and allows new species to be grown in regions previously unsuitable for them, but such changes are very much localized and can have profound effects on society, especially those of economic dependency on a few export commodities. Climate change is driven by a multitude of factors and the result is spatially uneven climatic disruptions. These changes are not taking place in a microthermsic economic system either; on the contrary, alterations in markets and policies place small farmers increasingly at risk. Selection of suitable crops, cropping systems, and soil management are critical to maintaining agriculture's cohesiveness in the face of climate change. Thus, social aspects, markets, and economics are now critical considerations in the search for improved sustainability. In regions of serious drought or water drainage, conservation of the surface phosphate balance becomes vital and when water is limited in supply it must be used efficiently for irrigation and dam and water management must take pre-eminence.

Rural development and land-use planning policy have changed fundamentally in the past decade. A great deal of support has been removed from large-scale, capital-intensive, monocultural agriculture in the developed, temperate economies and significant financial resources now are being made available for investment in rural development in less-developed countries. It is within this context that land-use changes have become increasingly apparent in areas of agricultural intensification and it is here where support for diffusion or emulation of innovations has been the key to changes in farming practice and progressive territorial development while in areas of remoteness and declining relative viability the monitoring of changes has been fundamental.

Conclusion

Regional case studies augmenting the general analysis demonstrate the ubiquity of these themes, while additional facets emerge from the geographical specifics of each region. In temperate Europe, land-use transitions and subsequent Environmental Policy Reforms exposing the unintended consequences of subsidies designed to alleviate rural poverty are analysed. In the Prairie and Great Plains regions of North America, the consolidation of farming operations and diversification into non-agricultural land uses are paralleled by the adoption of newer cropping practices. Elsewhere in the world, evidence from East Asia, Sub-Saharan Africa and the South American agro-frontier illustrate intensification, territorial expansion, smallholder resilience despite increasing actor capacities and adaptive cycles reinforcing or countering ecological impacts on biodiversity and natural resources.

The synthesis reinforces the importance of markets, infrastructure, institutions and ecosystems in the specification of land-use choices and the dynamics of land use change. The consideration of proximate and ultimate causes fosters a better understanding of agricultural land use beyond the dominant preoccupation with increasing production. The prospects for such land uses to contribute to sustainability objectives are too often discounted on the basis of dominant agricultural practice rather than recognition of trends toward mainstreaming environmental concerns. General climate change adaptation and mitigation pathways, illustrated within policy-specific contexts, distil the contributions of these approaches into tractable recommendations for land-use decision-makers at all levels.

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