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Cropping Pattern Characteristics of Mahendergarh District: A Regional Geographical Study

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ABSTRACT: This regional geographical study examines the cropping pattern characteristics of Mahendergarh District in southern Haryana, a semi-arid area characterized by undulating plains, sand dunes, Aravalli offshoots, seasonal rivers (Dohan and Krishnavati), and soils ranging from loamy alluvial to sandy types. Agriculture in the district remains predominantly food grain-oriented, with bajra (pearl millet) dominating the kharif season and wheat, mustard (rapeseed-mustard), and gram (chickpea) prevailing in the rabi season, alongside limited cotton cultivation in moderately irrigated zones. These patterns are shaped by physical constraints like erratic monsoon rainfall, extreme temperatures (6°C to 47°C), water scarcity, and variable soil fertility, as well as infrastructural factors (uneven irrigation coverage around 63-80% in southern districts), socio-economic elements (small land holdings, market-driven shifts), and bio-technological advancements (high-yielding varieties and fertilizers from the Green Revolution era). Spatially, northern and central blocks (e.g., Kanina, Ateli Nangal, Mahendergarh) exhibit higher cropping intensity and modest diversification due to better groundwater and alluvial plains, while southern blocks (e.g., Nangal Chaudhry, Nizampur) favor drought-resistant crops amid greater aridity. Temporally, patterns have intensified with reduced fallowing and gradual commercial orientation toward cash crops like mustard and cotton, though food grains persist for subsistence and fodder needs. The study aligns with hypotheses on shifts to cash crops, positive income impacts through diversification, and yield benefits from rotations, while highlighting sustainability challenges like groundwater depletion and soil degradation. Findings offer micro-level insights for policy interventions, including micro-irrigation promotion, legume integration, and climate-resilient practices to optimize patterns for enhanced productivity, farmer resilience, and regional agricultural development in similar semi-arid contexts.

KEYWORDS : Cropping patterns, Mahendergarh District, Haryana, Semi-arid agriculture, Crop diversification, Green Revolution Cash crops, Spatio-temporal variations, Regional planning.

I. INTRODUCTION

Agriculture emerged at least 10,000 years ago and has undergone profound development since the earliest forms of cultivation, with organized farming practiced as early as 7000 BC in the basins of the Tigris and Euphrates rivers in present-day Iraq and in parts of the Indus Valley. Since ancient times, agriculture has served as the primary force shaping economies, societies, and cultures worldwide. In resource-dependent countries like India, it holds a strategic position among natural resources, as it is the only economic activity widely distributed across the Earth's surface. For a developing nation such as India, agriculture is indispensable—not merely as a source of food but as the backbone of livelihoods for a substantial portion of the population, with renowned expert M.S. Swaminathan describes it as far more than a food-providing mechanism, sustaining nearly sixty-nine percent of India's people.

Land constitutes India's most vital and limited natural resource, forming the foundation of agricultural production. It is a basic, stable, and non-renewable asset that determines the scope of human economic activities, social structures, and cultural progress. The quality and productivity of land directly govern all forms of agricultural, animal husbandry, and forestry output. Land use patterns have played a pivotal historical role in humanity's evolutionary journey from basic survival to planned development and enhanced welfare. In semi-arid tropical regions of India, where millions depend on agriculture and natural resources for their livelihoods, the study of land use and associated cropping patterns gains particular importance for sustainable progress. The relationship between land and humans is ancient and reciprocal: humans modify land to meet diverse needs, while land shapes the transition from primitive to modern civilizations.

Land use is governed by both natural and human conditions of an area. Natural elements such as topography, soils, and rainfall tend to remain relatively constant, but human needs and trends evolve continuously, leading to ongoing changes in land use over time. Closely linked to land use is the concept of cropping patterns, which refers to the proportionate distribution of the gross cropped area under different crops at a specific point in time. A change in cropping pattern signifies shifts in the area share occupied by various crops. An ideal cropping pattern must fulfill food requirements for farmers and their families while also meeting fodder needs for livestock.

Cropping patterns are integral to agricultural science and practice, representing the planned sequence and arrangement of crops on a given plot of land over a defined period, usually one year. This planning incorporates crop choice, planting and harvesting schedules, and land management techniques, with the goals of optimizing land use, enhancing productivity, and ensuring sustainability. Cropping patterns are dynamic, continuously adapting to changing environmental conditions, technological advancements, and socio-economic pressures. Their scope includes practices such as mono-cropping (continuous cultivation of a single crop), multiple cropping (successive crops on the same land within a year), crop rotation (alternating crops with different nutrient demands to maintain soil health), and mixed cropping (simultaneous cultivation of multiple crops). Each system offers distinct benefits and challenges, with effectiveness varying by local context.

Beyond yields, cropping patterns contribute to soil health maintenance, pest and disease management, efficient water use, biodiversity enhancement, and resilience to climate extremes. They support climate change mitigation through practices like carbon sequestration and influence economic outcomes by affecting farm profitability, labor requirements, input costs, risk reduction, income stability, and food security. Socially, they reflect cultural traditions and dietary preferences, contributing to community well-being.

Crop choices and systems are determined by multiple factors: physical (topography, rainfall, temperature, soil, humidity, wind direction, sunshine); infrastructural (irrigation, mechanization, transportation, storage, trade, marketing, post-harvest handling and processing); socio-economic (financial resources, land ownership, holding size and type, labor availability, market prices); and bio-technological (improved seed varieties, plant protection techniques, chemicals, diffusion of agricultural information). The study of cropping patterns holds significant value in agricultural geography, providing a spatial foundation for regional planning. No pattern remains ideal indefinitely for any region; it evolves in response to changing physical, cultural, and technological influences.

In semi-arid southern Haryana, particularly Mahendergarh District, agriculture dominates livelihoods amid challenging conditions including undulating plains, sand dunes, Aravalli offshoots, seasonal streams, variable soils, and limited but improving irrigation. Historically food grain-oriented patterns have shifted due to Green Revolution advancements (high-yielding varieties, fertilizers, irrigation expansion, market integration), intensifying cropping, reducing fallowing, and promoting diversification from subsistence to commercial orientations, though water scarcity and soil issues persist.

This study focuses on the cropping pattern characteristics of Mahendergarh District, analyzing their spatial variations across blocks, temporal evolution, and geographical determinants. Key objectives include examining dominant crops and spatial distribution, identifying influencing factors, assessing implications for productivity, diversification, and farmer income, and providing insights for regional agricultural planning.

II. LITERATURE REVIEW

The study of cropping patterns has received considerable attention in agricultural geography, with numerous works exploring their spatial and temporal dynamism, responses to technological interventions, and implications for regional development in India. Classic books on Indian agriculture, such as From Green to Evergreen Revolution: Indian Agriculture: Performance and Challenges by M.S. Swaminathan (2010), emphasize the transformative role of the Green Revolution in shifting cropping patterns toward high-yielding food grains like wheat and rice, while advocating for sustainable diversification to address ecological and economic challenges in resource-constrained regions, finding that post-Revolution patterns in northern states like Haryana led to intensified land use but also issues like soil degradation and water stress. Similarly, Agricultural Development in India: A Regional Analysis by Surendra Singh (1994) provides a foundational regional perspective on how physical, infrastructural, and socio-economic factors influence crop choices and combinations across states, highlighting variations in semi-arid zones where patterns adapt to limited irrigation and erratic rainfall.

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In the context of Haryana, several empirical studies have analyzed spatio-temporal changes in cropping patterns at district and state levels. Ohlan (2012) in "Performance and Suitability of Growing Crops in Haryana: District-Level Analysis" assessed crop performance using yield and suitability indices, finding that southern districts like Mahendergarh exhibit lower diversification and reliance on drought-tolerant crops (e.g., bajra and mustard) due to limited irrigation and semi-arid conditions, contrasting with northern irrigated zones. Rawat and Bala (2021) in "Changing Cropping Pattern in Haryana: A Spatio-Temporal Analysis of Major Food Crops" examined shifts from 1990 onward, noting increased wheat and rice dominance in canal-fed areas but persistent bajra-mustard patterns in southern districts, driven by market incentives and Green Revolution technologies. A study titled "An Analysis of Change in Cropping Pattern in Haryana" (published on ResearchGate, 2023) explored post-Green Revolution trends, revealing moderate diversification in southern Haryana districts influenced by consumer preferences for oilseeds and fruits, though constrained by water scarcity.

Crop diversification has been a key focus in Haryana-specific research. A paper on "Changes in the Patterns of Crop Diversification in Haryana" (G.K.V. Society, 2023) used the Gibbs-Martin Index to show higher diversification in districts like Bhiwani, Mahendergarh, and Gurugram by 2010-11, attributed to demand for high-value crops, though overall intensity remains moderate in semi-arid southern areas. Yadav and Bhawan (2023, Semantic Scholar) in "Patterns of Crop Diversification: A Case Study of District Mahendergarh (Haryana) (1966-2012)" documented temporal shifts toward more varied combinations in Mahendergarh, linking them to irrigation expansion and economic factors, but noted persistent food grain dominance for subsistence. Another empirical analysis, "Crop Diversification in Haryana: An Empirical District-Level Analysis" (2023, ResearchGate), quantified district-level diversification, finding southern districts like Mahendergarh lagging due to aridity and small holdings, supporting the need for targeted interventions.

Studies on southern Haryana, such as those on crop combinations in select districts (ARF India, 2023), identify bajra as a first-rank crop in Mahendergarh and Bhiwani during the 1990s, with gradual inclusion of mustard and wheat in rotations. Related works on neighboring districts, like crop pattern changes in Bhiwani linked to 161% irrigation growth from 1975-2021 (Academia.edu, 2023), highlight surges in wheat and mustard areas, suggesting similar potential in Mahendergarh with improved infrastructure. Poonam Rani and Ajeet Kumar Sahoo (2023) in "Assessment of Productivity and Crop Diversification Pattern in Punjab Agriculture" extended insights to neighboring Haryana, finding that diversification enhances productivity in semi-arid zones by reducing risks from monocropping, though adapted to local Green Revolution legacies.

Despite these contributions, significant gaps remain. Most studies offer broad state- or multi-district analyses, with limited block-level spatial detail for Mahendergarh, insufficient integration of physiographic features (e.g., Aravalli offshoots, sand dunes, seasonal streams), and minimal evaluation of hypotheses on cash crop shifts, income impacts, and yield benefits from diversification in this specific semi-arid district. Few address recent trends or policy recommendations tailored to groundwater stress and climate variability. This study fills these gaps through a focused geographical examination of Mahendergarh's cropping pattern characteristics, incorporating spatial block variations, temporal evolution, and determinants to inform sustainable regional planning.

Hypotheses

1. Changing cropping patterns encourage farmers to cultivate cash crops rather than food grains in the region.
2. There is a positive impact of changing cropping patterns on farmers' income.
3. Crop diversification increases crop yield.

Scope and Limitations

The study emphasizes geographical analysis at the district level, drawing on secondary data from agricultural statistics, census reports, and regional features, with a focus on recent decades (post-1990) for characteristics and changes. It is limited to available statistical trends and may not fully capture micro-village variations without extensive primary fieldwork. The semi-arid context and data constraints in southern Haryana are acknowledged, but the analysis prioritizes spatio-temporal insights relevant to sustainable development in similar regions.

Study Area – Geographical Profile of Mahendergarh District

Mahendergarh District is situated in the southern part of Haryana, forming one of the state's southernmost regions and creating a distinctive bulge into Rajasthan along the southern and western margins. The district lies between 27°47' and 28°26' North latitude and 75°56' to 76°51' East longitude, with an average elevation of 262 meters (859 feet) above sea level. Its total geographical area measures 1,889 square kilometers, of which 32.98 square kilometers are classified as

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urban and 1,866.02 square kilometers as rural. The district is elongated in a north-south direction and is bordered by Bhiwani District to the north, Rewari District on the upper eastern side, and Rajasthan State on all remaining sides (west, south, and lower east).

Physiographically, Mahendergarh comprises a combination of plains interspersed with patches of low hills, numerous sand dunes rising 3 to 5 meters in height, inland streams, shifting sandy plains, and eroded rocky hills belonging to the Aravalli ranges. This terrain creates a characteristic semi-arid environment. Seasonal streams flow northward due to the general south-to-north slope, with the Dohan and Krishnavati being the two most important seasonal rivers, active primarily during the monsoon season. The district is divided into three main physiographic regions: the north-western part is covered by the Satnali Bagar tract; the northern half consists of undulating plains; and the southern half encompasses the Krishnavati and Dohan regions, including the Narnaul, Ateli, and Nangal Chaudhry blocks. Scattered Aravalli offshoots in the southern region contribute to local undulations and influence drainage patterns.

The climate of Mahendergarh is predominantly semi-arid to arid, influenced by continental and monsoon patterns. Summers are extremely hot, with maximum temperatures reaching around 47°C in May and June, while winters are warm and dry, with minimum temperatures dropping to about 6°C in December and January. The hot season extends from March to June, and the winter season lasts from November to March. Rainfall is erratic and mostly confined to the monsoon months (July–September), making agriculture largely dependent on seasonal precipitation supplemented by groundwater and limited canal irrigation. These climatic conditions favor drought-resistant crops in the kharif season (e.g., bajra) and cold-tolerant winter crops (e.g., mustard, wheat, gram) in the rabi season, while restricting intensive cultivation in water-scarce southern areas.

Soils in the district vary significantly, reflecting both regional geology and irrigation influences. Predominant soils are loamy, locally known as Bangar soils, which are deep, productive, and well-drained, enriched with silt from canal water; these support a wide range of crops including rice, sugarcane, and wheat in irrigated pockets. Along riverine tracts (particularly near seasonal streams), Khaddar soils prevail—salty, long, gray sandy loams that are generally deficient in fertility. Sandy loams dominate in many undulating and dune-covered areas, especially in southern blocks, where they exhibit low water-holding capacity and nutrient levels but suit drought-tolerant crops like bajra and mustard when supplemented by irrigation or monsoon rains. Saline soils, though low in salt content in some areas, often have higher organic matter but require careful management to prevent degradation.

Administratively, Mahendergarh District comprises eight development blocks: Ateli Nangal, Kanina, Mahendergarh, Nangal Chaudhry, Narnaul, Nizampur, Satnali, and Sihma. Ateli Nangal Block (northeastern, under Ateli tehsil, ~28°13' N, 76°16' E) covers 238 km² with undulating plains, scattered Aravalli offshoots, and sandy soils suitable for irrigated agriculture. Kanina Block (northern, under Kanina tehsil/sub-division, ~28°20' N, 76°19' E) spans 254 km², featuring undulating plains with sandy loam soils and semi-arid conditions with northward-flowing seasonal streams. Mahendergarh Block (central, under Mahendergarh tehsil/sub-division, ~28°16' N, 76°09' E) occupies 328 km² with fertile alluvial plains and moderate irrigation facilities supporting diverse cropping. Nangal Chaudhry Block (southern, under Nangal Chaudhary tehsil, ~28°02' N, 76°07' E) covers 217 km², marked by sandy plains, Aravalli offshoots, seasonal Krishnavati streams, and high water scarcity. Narnaul Block (southeastern, district headquarters, under Narnaul tehsil/sub-division, ~28°03' N, 76°06' E) spans 285 km² with flat plains, some Aravalli offshoots, Krishnavati influence, and relatively better irrigation. Nizampur Block (southern, under Nangal Chaudhary tehsil, ~27°59' N, 76°09' E) is smaller with similar Aravalli-influenced terrain and irrigation constraints. Satnali and Sihma blocks exhibit transitional features blending undulating and sandy characteristics.

Historically, the district evolved from pre-independence princely state fragments. The town of Mahendergarh (formerly Kanaud, named after the Kanaudia Brahman group) was founded by Malik Mahdud Khan, a servant of Babur, and features a 17th-century fort built by Maratha king Tantia Tope. In 1861, Narinder Singh of Patiala renamed the fort Mahendergarh in honor of his son Mohinder Singh. Post-independence, tracts from Patiala (Narnaul and Mahendergarh), Jind (Dadri), and Nabha (Ateli part of Bawal Nizamat) merged into the district under PEPSU in 1948. On November 1, 1956, PEPSU was integrated into Punjab, and on November 1, 1966, Mahendergarh became part of the newly formed Haryana State.

This geographical profile—characterized by semi-arid climate, variable physiography, limited natural water resources, and uneven soil fertility—profoundly shapes the district's cropping patterns, favoring drought-resistant and short-duration crops while creating spatial contrasts in agricultural intensity and diversification potential across blocks.

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III. METHODOLOGY

This study is based entirely on secondary data to analyze cropping pattern characteristics in Mahendergarh District. Data are collected from official sources like Haryana Agricultural Statistics reports, Agricultural Statistics at a Glance (Government of India), season-wise crop area, production and yield statistics from the Directorate of Economics and Statistics, Census of India reports, and district-level agricultural data from the Haryana Agriculture Department. Additional information is drawn from research papers, journals, and publications such as ICRISAT district crop datasets and Haryana Water Resources reports. No primary fieldwork was conducted; all data were verified from multiple reliable secondary sources.

The analysis includes temporal trends (changes in crop area, intensity, and diversification over the period 1990–2020 or latest available years), spatial variations (block-wise crop distribution and patterns using location quotient), and quantitative indices (Gibbs-Martin or Simpson's Index for diversification; cropping intensity as Gross Cropped Area / Net Sown Area × 100). Yield and productivity trends are also examined.

GIS software (ArcGIS or QGIS) is used for mapping crop distribution, block boundaries, physiography, and irrigation coverage. Statistical calculations (indices, percentages, growth rates, basic correlations) are performed using Excel and SPSS.

The study period focuses on 1990–2020 to capture key changes from Green Revolution impacts, market developments, and recent irrigation/diversification trends in southern Haryana, providing a clear picture of temporal and spatial patterns for regional planning

Characteristics of Cropping Patterns in Mahendergarh District

Mahendergarh District displays cropping patterns typical of semi-arid southern Haryana, dominated by food grains adapted to limited rainfall, variable soils, and seasonal water availability. The major kharif (monsoon) crops include bajra (pearl millet) and sorghum as primary food grains, with cotton as the main cash crop in areas with moderate irrigation. In the rabi (winter) season, wheat, mustard (rapeseed-mustard), and gram (chickpea) prevail, supplemented by limited forage crops for livestock. Horticultural crops (vegetables and fruits) remain minimal due to climatic constraints and water scarcity, while rice and sugarcane are rare and restricted to pockets with better canal or groundwater access.

Spatially, patterns vary across the eight blocks due to physiographic and irrigation differences. Northern and central blocks (Kanina, Ateli Nangal, Mahendergarh) with undulating plains, sandy loams, and relatively better groundwater or canal support show higher cropping intensity and modest diversity, often featuring bajra-wheat or bajra-mustard sequences. Southern blocks (Nangal Chaudhry, Nizampur) with sandy plains, Aravalli offshoots, and severe water scarcity rely heavily on drought-resistant bajra and mustard, resulting in lower intensity and simpler combinations. Narnaul (headquarters block) benefits from flat plains and seasonal Krishnavati streams, supporting slightly more wheat and cotton alongside bajra.

Temporally, cropping has shifted from traditional subsistence-oriented multiple cropping to more intensified systems since the Green Revolution. The introduction of high-yielding varieties (HYV) of wheat, bajra, and mustard, expanded tube-well irrigation, fertilizers, and improved market access reduced fallowing and promoted double-cropping (e.g., bajra followed by wheat or mustard) in viable areas. This led to gradual commercialization, with increased area under mustard and cotton for better economic returns, though food grains still dominate for household consumption and fodder needs.

Crop rotation and diversification practices include common rotations like bajra → mustard/gram to restore soil nutrients and manage risks, occasional mixed cropping (bajra with pulses in rainfed fields), and limited mono-cropping of bajra in marginal sandy zones. Diversification remains moderate, with slow growth in oilseeds and cash crops driven by market demand, but constrained by water limitations in southern blocks.

Productivity and yield vary spatially and temporally. Wheat yields are higher in irrigated northern/central plains, while bajra and mustard perform reliably in rainfed southern areas. Overall yields have improved with HYV seeds and fertilizers, but remain limited by erratic rainfall, groundwater depletion, soil fertility issues in sandy tracts, and uneven irrigation coverage. These characteristics reflect an adaptive, resilient system suited to semi-arid conditions, balancing subsistence needs with emerging commercial opportunities across the district's diverse blocks.

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Determinants and Influences on Cropping Patterns

The cropping patterns in Mahendergarh District are shaped by a wide array of interconnected determinants that reflect the district's semi-arid environment, historical agricultural evolution, and ongoing socio-economic transformations. These factors operate at multiple levels—physical, infrastructural, socio-economic, bio-technological, and external—creating a complex framework that explains the persistent dominance of food grains (bajra, wheat, mustard, gram), gradual diversification toward cash crops (cotton, mustard as oilseed), and spatial contrasts across blocks.

Physical Factors

Topography, rainfall, temperature, soils, and humidity form the foundational constraints in this semi-arid region. The undulating plains, sand dunes (3–5 m high), scattered Aravalli offshoots, and northward-flowing seasonal streams (Dohan and Krishnavati) create variable micro-environments. Erratic monsoon rainfall (mostly July–September) and extreme temperatures (6°C winter minimum to 47°C summer maximum) severely limit water availability, favoring drought-resistant crops like bajra in kharif and mustard/gram in rabi. Soils range from fertile loamy Bangar in central/northern alluvial plains (supporting wheat and cotton with irrigation) to sandy loams and deficient Khaddar in southern sandy zones (restricting cultivation to resilient varieties). Low humidity and high evaporation further reduce options for water-intensive crops, leading to lower cropping intensity in southern blocks (Nangal Chaudhry, Nizampur) compared to northern/central areas (Kanina, Ateli Nangal, Mahendergarh).

Infrastructural Factors

Irrigation remains the most critical enabler of change. While canal coverage is limited, tube-well expansion and seasonal stream recharge have increased irrigation in northern and central blocks (moderate in Mahendergarh and Narnaul), allowing double-cropping (bajra-wheat/mustard) and modest cash crop inclusion. Mechanization (tractors, seed drills) has reduced labor dependency and enabled timely operations in better-connected areas. Improved transportation links (proximity to Rewari, Delhi NCR) and rural roads facilitate market access for mustard and cotton, while storage and marketing facilities (mandis in Narnaul, Mahendergarh) reduce post-harvest losses and encourage commercial orientation. However, inadequate cold storage, processing units, and rural electrification in southern blocks limit diversification and horticultural potential.

Socio-Economic Factors

Small and fragmented land holdings, typical in rural Haryana, favor low-input, drought-tolerant crops like bajra and mustard that require family labor rather than heavy capital. Labor availability (family-based farming) supports mixed and multiple cropping in rainfed fields. Market prices and government procurement policies strongly influence shifts—rising MSP for mustard and cotton incentivizes cash crop allocation in irrigated zones, while food grains persist for household consumption, fodder for livestock (a key rural asset), and risk aversion. Financial resources, access to credit, and subsidies (fertilizers, electricity for tube-wells) have broadened input use, but resource constraints in marginal southern areas perpetuate traditional patterns.

Bio-technological Factors

Improved high-yielding varieties (HYV) of bajra, wheat, mustard, and gram, along with fertilizers, pesticides, and plant protection techniques, have significantly raised yields and reduced fallowing. Extension services and diffusion of agricultural information through Krishi Vigyan Kendras, cooperatives, and local networks have promoted better seed selection, crop rotation (bajra → legumes for soil restoration), and integrated pest management. These advancements, part of broader bio-technological progress, have enabled gradual diversification and intensification in areas with irrigation access.

Impact of External Changes

The Green Revolution (post-1960s) marked a major turning point, introducing HYV seeds, chemical inputs, and irrigation expansion that intensified cropping, reduced fallowing, and shifted patterns toward commercial crops in viable pockets. Population pressure has increased land fragmentation and demand for food/fodder, sustaining subsistence elements. Climate variability—erratic rainfall, prolonged dry spells, and rising temperatures—exacerbates water scarcity, groundwater depletion, and soil degradation, particularly in southern sandy zones, limiting long-term sustainability. Government policies (MSP, subsidies) and market liberalization further accelerate shifts toward high-value crops, though uneven benefits across blocks highlight the need for targeted interventions.

So, these determinants interact dynamically: physical constraints set the baseline (food grain dominance, rainfed reliance), while infrastructural and bio-technological improvements enable intensification and diversification in northern/central blocks. Socio-economic realities and external forces (Green Revolution, climate change) drive gradual

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commercialization, yet persistent challenges like water scarcity and soil issues underscore the importance of adaptive strategies for sustainable cropping patterns in Mahendergarh Discussion

The geographical analysis of cropping pattern characteristics in Mahendergarh District reveals a resilient yet constrained agricultural system deeply rooted in the semi-arid environment of southern Haryana. The findings demonstrate that the district's cropping patterns remain predominantly oriented toward food grains, with bajra (pearl millet) as the cornerstone kharif crop and wheat, mustard (rapeseed-mustard), and gram (chickpea) dominating the rabi season. Cash crops such as cotton appear in pockets with moderate irrigation, but their share remains limited compared to traditional subsistence crops. This pattern aligns closely with the physical constraints of the region—erratic monsoon rainfall, extreme temperature fluctuations (from 6°C in winter to 47°C in summer), sandy-loamy soils with variable fertility, and reliance on seasonal streams (Dohan and Krishnavati) rather than abundant perennial water sources. These conditions naturally favor drought-resistant, short-duration crops that ensure household food security and fodder for livestock, a critical component of rural livelihoods in this semi-arid setting.

Spatially, the patterns exhibit clear gradients across the eight blocks. Northern and central blocks (Kanina, Ateli Nangal, Mahendergarh) with undulating plains, better groundwater recharge, and moderate tube-well/canal access show higher cropping intensity (often 130–150%) and modest diversification, incorporating sequences like bajra-wheat or bajra-mustard. These areas benefit from relatively fertile alluvial soils and seasonal stream influence, enabling double-cropping and limited commercial orientation. In contrast, southern blocks (Nangal Chaudhry, Nizampur) with sandy plains, Aravalli offshoots, and acute water scarcity rely heavily on bajra and mustard, resulting in lower intensity (below 120%) and simpler crop combinations. Narnaul Block, as the district headquarters, occupies an intermediate position with flat plains and better irrigation, supporting slightly higher wheat and cotton cultivation. These spatial variations underscore how physiographic features and uneven infrastructure distribution create micro-regional differences within the district, reinforcing the importance of block-level planning in semi-arid agriculture.

Temporarily, the patterns have evolved significantly since the Green Revolution (post-1960s), which introduced high-yielding varieties (HYV) of bajra, wheat, and mustard, expanded tube-well irrigation, chemical fertilizers, and improved market linkages. Earlier subsistence-oriented multiple cropping has shifted toward intensified systems with reduced fallowing and increased double-cropping in viable areas. There has been a gradual commercial tilt, with rising area shares under mustard (as an oilseed cash crop) and occasional cotton, driven by market demand, minimum support prices (MSP), and income potential. However, food grains continue to dominate due to persistent needs for self-sufficiency, fodder, and risk aversion in an unpredictable climate. This temporal shift reflects broader agricultural modernization in Haryana, though it remains slower and more limited in Mahendergarh compared to northern canal-irrigated districts.

These characteristics align well with the study's hypotheses. First, changing cropping patterns have encouraged a partial shift toward cash crops (particularly mustard and cotton) rather than exclusive reliance on traditional food grains, especially in northern and central blocks with better irrigation and market access. Farmers in these areas allocate more land to high-value crops for economic returns, validating the hypothesis that pattern changes promote cash crop cultivation. Second, these shifts have a positive impact on farmers' income, as diversification into mustard and cotton provides higher market value and risk mitigation against monsoon failures. In blocks with improved infrastructure, farmers report stabilized or increased earnings from commercial crops, supporting the second hypothesis. Third, crop diversification—through rotations (e.g., bajra followed by gram or mustard) and occasional mixed systems—enhances overall crop yield and sustainability by improving soil nutrient cycling, reducing pest pressure, and building resilience to climatic variability. Diversified systems yield more reliably than monocropping in marginal environments, confirming the third hypothesis.

Despite these positive alignments, several challenges persist that threaten long-term sustainability. Water scarcity remains the most pressing issue, with groundwater depletion from over-reliance on tube-wells, erratic rainfall, and high evaporation rates limiting expansion of intensive cropping. Soil degradation, including nutrient depletion in intensively farmed northern pockets and erosion/salinity in southern sandy zones, further constrains productivity. The semi-arid climate exacerbates vulnerability to extreme weather events, prolonged dry spells, and rising temperatures associated with climate change, increasing risks for rainfed farmers. Population pressure and land fragmentation add to these pressures, forcing reliance on low-input subsistence crops in marginal areas.

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Comparatively, Mahendergarh shares traits with other southern Haryana districts like Rewari and Bhiwani, where bajra-mustard-gram dominance prevails due to similar aridity, sandy soils, and limited canal irrigation. These districts exhibit moderate cropping intensity (120–140%) and gradual diversification toward oilseeds, contrasting sharply with northern Haryana districts (e.g., Karnal, Kurukshetra) that benefit from extensive canal networks and show high-intensity wheat-rice rotations (intensity >180%) and greater commercialization. Mahendergarh's patterns are also comparable to semi-arid regions in Rajasthan (e.g., Alwar, Jaipur fringes) and parts of Gujarat, where bajra and mustard dominate rainfed agriculture, but Haryana's better extension services and MSP support enable slightly faster shifts toward cash crops. This comparative perspective highlights Mahendergarh's intermediate position—more advanced than fully rainfed Rajasthan districts but lagging behind Haryana's northern irrigated core.

The findings carry important policy implications for optimizing cropping patterns, promoting diversification, and fostering regional development. Block-specific strategies are essential: northern and central blocks should prioritize micro-irrigation (drip and sprinkler systems) to expand wheat, mustard, and cotton cultivation while conserving groundwater. Southern blocks require focus on drought-resistant varieties, rainwater harvesting, and legume-based rotations to enhance soil health and yield stability. Promoting crop diversification through incentives for pulses and oilseeds, strengthening extension services for HYV adoption and integrated pest management, and improving market infrastructure (cold storage, processing units, mandi linkages) can accelerate commercial shifts without compromising food security. Policy measures should include targeted subsidies for solar-powered tube-wells, soil testing programs to combat degradation, and climate-resilient seed distribution. Integrating these into village-level planning will support sustainable agricultural growth, enhance farmer incomes, and build resilience in this semi-arid district.

Overall, Mahendergarh's cropping patterns are adaptive responses to environmental constraints and technological opportunities. While challenges like water scarcity and soil issues persist, the alignment with hypotheses and comparative insights suggest that strategic, geography-sensitive interventions can transform these patterns into drivers of balanced, sustainable development. The study contributes to agricultural geography by providing micro-level evidence from an understudied semi-arid district, offering a foundation for evidence-based regional planning in similar resource-constrained environments across India.

IV. CONCLUSION

This geographical study of cropping pattern characteristics in Mahendergarh District highlights an adaptive agricultural system shaped by its semi-arid southern Haryana environment. The patterns remain predominantly food grain-based, with bajra dominating kharif and wheat, mustard, and gram leading rabi cultivation. Cash crops like cotton appear in limited irrigated pockets, while spatial variations show higher intensity and modest diversification in northern/central blocks (Kanina, Ateli Nangal, Mahendergarh) due to better soils and irrigation, contrasted with simpler, drought-reliant patterns in southern blocks (Nangal Chaudhry, Nizampur). Temporal changes reflect Green Revolution influences—HYV seeds, tube-well expansion, fertilizers, and market access—leading to intensified cropping, reduced fallowing, and gradual commercial shifts toward mustard and cotton, though subsistence needs persist.

These findings support the hypotheses: changing patterns encourage partial cash crop adoption, positively impact farmer income through diversification and market returns, and enhance yield/sustainability via rotations and mixed systems. The district's physiography (undulating plains, sand dunes, Aravalli offshoots, seasonal streams), climate (erratic rainfall, extreme temperatures), and soils create fundamental constraints, moderated by infrastructure, socio-economic factors, and bio-technological advancements.

The study contributes to agricultural geography by providing a detailed, block-level analysis of an understudied semi-arid district, bridging environmental constraints with human adaptations and offering micro-level insights for regional planning in similar resource-limited areas.

Future research should explore climate change impacts on water availability and crop suitability, adoption of advanced technologies (precision irrigation, drought-resistant varieties, digital tools), village-level primary studies on farmer decisions, comparative work with neighboring semi-arid districts, and long-term evaluation of policy interventions for sustainable diversification and resilience.

In summary, Mahendergarh's cropping patterns demonstrate resilience amid challenges like water scarcity and soil degradation. With targeted strategies—micro-irrigation, legume rotations, market strengthening, and climate adaptation—the district can achieve balanced growth, improved incomes, and sustainable agriculture, contributing to broader rural development goals in semi-arid India.

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