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Sunspot Theory and Agricultural Decision Making: Implications for Rural Development (A Thematic Review and Critical Synthesis)

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Abstract

Sunspot theory's role in agriculture is an intriguing concept that could benefit farmers facing climate challenges. The present article has reviewed numerous studies on solar physics and its indirect effects on agriculture and farmers' livelihoods, with a particular focus on Pakistan. This article discusses how the sunspot cycle affects climate patterns, crop production, commodities, and individual farmers. In turn, these impacts are reviewed in-depth in the final section of the article. This article suggests that sunspot-related variations in climate could have a noticeable effect on regional crop production. Changes in rainfall patterns associated with solar cycles can lead to agricultural issues such as pests and drought. This article explores these connections in-depth and applies them to South Asia, sub-Saharan Africa, and Pakistan. In addition, discusses the effect of climate and food shortages on farmers' livelihoods. The study notes that many factors beyond solar activity, such as land ownership, gender-specific challenges, and government policies, contribute to food shortages in Pakistan. By organizing studies into thematic frameworks rather than cataloguing individual contributions, this review identifies research gaps and policy pathways for embedding solar-cycle intelligence into agricultural decision-making systems.

Keywords: Sunspot theory, Solar cycle variability, Agricultural decision-making, Climate-informed rural development, Smallholder vulnerability, Monsoon dynamics, Institutional reform, Pakistan

1. Introduction

The relationship between solar activity and terrestrial agriculture represents one of the longest-running research programs in the natural and social sciences, tracing its lineage to Herschel's 1801 speculation that sunspot counts might correlate with wheat prices (Jones, 1978). This review addresses how knowledge of solar magnetic cycles can improve agricultural decision-making in an era of accelerating climate change, through systematic thematic synthesis of evidence spanning solar physics, climatology, agricultural economics, and rural development.

Three converging developments motivate this synthesis. First, advances in solar physics particularly the extended solar cycle framework and Hale cycle clock, suggest that the 22-year Hale magnetic cycle, rather than the conventional 11-year Schwabe sunspot cycle, may be the relevant periodicity for climate-forcing studies (McIntosh *et al.*, 2021; Leamon *et al.*, 2022; Martin, 2024). Second, escalating climate extremes in agriculturally dependent regions exemplified by Pakistan's 2022 floods that submerged 45 percent of national cropland and triggered unprecedented food price inflation (Sohail *et al.*, 2023) have intensified the search for predictive frameworks. Third, refined climate teleconnection models have established plausible mechanisms by which solar forcing drives regional precipitation patterns which ultimately affect crop production (Kodera *et al.*, 2007; Ambily *et al.,* 2020; Berntell *et al.*, 2018).

This study has three major contributions, identified as part of the review. It first aims at synthesizing the evidence along the causal chain from solar magnetic activity to regional teleconnections of climate and agriculture, highlighting the role of the intervening socioeconomic processes. Second, contrasts and comparisons between the different methodologies, regional settings and theoretical approaches used in solar terrestrial physics are highlighted, by explicitly including them in the review story. Last but not least, the review highlights gaps in research and suggests research directions.

2. Review Methodology

2.1. Review Design

This review uses a structured narrative method, which is warranted because of the various and interdisciplinary nature of the evidence base. Due to the variety of study designs, a completely systematic review and meta-analysis was considered to be inappropriate. The approach is based on guidelines given in PRISMA 2020 (Page et al., 2021), if applicable.

2.2. Literature Search Strategy

A search was carried out using the search engines: Scopus, Web of Science, Google Scholar, JSTOR, ScienceDirect, SpringerLink and Wiley Online Library. The Boolean operators used in the search strings were: AND and OR.The Boolean operators used in search string were AND and OR. The database queries were complemented by backward and forward citation searches. Empirical evidence gaps were compiled from gray literature from FAO, IWMI and institutional repositories.

2.3. Inclusion and Exclusion Criteria

Table 1: Inclusion and Exclusion Criteria

Criterion	Specification
Publication period	1801 to 2025; emphasis on 2000 to 2025
Language	English
Document types	Peer-reviewed articles, books, dissertations, institutional reports
Subject relevance	Solar variability relationships with climate systems, agricultural productivity, commodity markets, or rural livelihoods
Geographic scope	Global; South Asia, sub-Saharan Africa; Pakistan prioritized
Exclusion criteria	Solar energy studies unrelated to solar cycles; publications without identifiable methodology

2.4. Study Selection, Data Extraction, and Synthesis

Around 200 records were retrieved from the database and among these approximately 50 different sources were selected after removing the duplicate and screened the records. The following were taken from each study: author(s), year, geographic focus, objectives, theory, methodology, key variables, findings, limitations, and policy implications. Researches were grouped into eight thematic areas. Informal assessment of quality was carried out using the aspects of methodological transparency, appropriateness and the reception into the discipline. The methodological heterogeneity was extreme and a formal critical appraisal tool was not used – this should probably be applied to specific methodological subsets of reviews in the future (e.g. CASP, JBI, MMAT).

3. Theoretical Background

3.1. From Schwabe to the Hale Cycle

Solar magnetic activity is now understood in a new way as being periodic in the modern era. The empirical basis was given by Schwabe's discovery of the roughly 11-year sunspot cycle in 1843, but there was a paradigm shift with the understanding that sunspots are only a component of the 22-year Hale magnetic cycle, as described by Martin (2024). McIntosh et al. (2021) demonstrated through 140 years of diagnostics that the Hale cycle operates with substantially greater regularity than sunspot records suggest, implying that climate-forcing studies should incorporate Hale cycle phasing. Leamon et al. (2022) developed the "solar cycle clock" framework, showing that 96 percent of extreme ultraviolet emissions which directly influence stratospheric dynamics occur within predictable Hale cycle phases.

Evidence from multiple timescales reinforces these conclusions. Owens et al. (2015) demonstrated the reality of the Hale cycle’s occurrence over a period of three centuries based on the data on cosmogenic radionuclides. Kotzé (2020) discovered the Schwabe, Gleissberg, and Hale cycles in tree-ring density records from Southern Africa during 1600-2000 AD. In particular, the Gleissberg cycle, which lasts 80-110 years, is most relevant to agricultural production since it affects a time frame that is adequate for strategic planning, during the Maunder minimum (1650-1715 AD), the length of the Schwabe cycle was 14 years, while solar cycles accounted for climate peculiarities observed in other proxies.

3.2. Physical Pathways and Theoretical Framework

Solar variability impacts climate in four main ways: total solar irradiance (TSI), ultraviolet (UV) spectral variability, solar wind influence on cosmic rays, and geomagnetic effects (Van Driel-Gesztelyi and Owens, 2020). The largest UV variability is more than an order of magnitude bigger than that of TSI and impacts the stratosphere’s ozone layer and temperatures. These processes are commonly referred to as “top-down” interactions, while the “bottom-up” processes are related to tropical oceans’ heating. However, the connection between solar activity and climate can be nonlinear and may involve time lags, as found in the analysis of wavelet coherence by Franke (2004). The connection can also change over time, which complicates the efforts to model it.

The paper will follow six steps from solar inputs to livelihoods through various mediating processes. First, solar magnetic dynamo and its effects, second, teleconnection processes in the atmosphere, third, surface climate processes, fourth, agricultural production, fifth, markets, and sixth, tenure, gender, credit, extension, and governance. This framework integrates solar physics, teleconnection theory, Moore's (1914) concept of "generating cycles," and sustainable livelihoods approaches to span the full disciplinary range of the reviewed literature.

4. Literature Review

This section presents findings organized into eight thematic categories, synthesizing studies into integrated narratives that compare findings and identify agreements and contradictions.

4.1. Solar Physics and Climate Mechanisms

The literature examined agrees on some conclusions: the basic magnetic cycle of Hale is 22 years; there are several radiative, dynamical, and particle pathways by which solar-climate connections might occur; and the solar-climate connections are non-stationary and subject to modulation by longer secular cycles. Adding to the complexity of detection, Rogers et al. (2006) found a secular cycle of 183–243 years in the length of sunspot cycles. But there are important uncertainties on the magnitude of the signal compared to internal climate variability and anthropogenic forcing. The TSI variation of about 0.1 per cent is small compared with the climate forcing due to greenhouse gases, and separating the solar contribution from natural climate variability is challenging. Better understanding of the propagation and amplification of weak periodic signals through and by the climate system is a needed ingredient for the movement from physical plausibility to agricultural predictability.

4.2. Regional Climate Teleconnections and Monsoon Dynamics

I start by talking about how the Sun affects monsoons, beginning in Asia. Ambily et al. (2020) have shown that the sunspot cycle has a significant impact on the long-term variability of Indian monsoon rainfall and droughts; that is, droughts tend to occur more often during minima in the sunspot cycle.

These authors analyze a 1200-year record of sunspot activity and demonstrate that secular trends in solar activity have been related to monsoon variability. A similar result is found by Chowdhury et al. (1981), who note that droughts tend to happen once every solar cycle, but with no clear timing in relation to maxima or minima, possibly indicating a varying degree of influence on monsoon variability. Kodera et al. (2007) identify a link between the IOD-ENSO coupled mode and solar cycles that may contribute to the monsoon patterns in Pakistan via the Indian Ocean and Pacific convergence zone.

The African Sahel represents another region where solar influences on monsoon variability have been identified. Berntell et al. (2018) find that decadal-scale Sahel rainfall anomalies are related to temperature anomalies in the North Atlantic, which in turn are linked to solar forcing. Zhang et al. (2022) highlight the role of anthropogenic aerosols in the North Atlantic, which modulate Sahel rainfall. These authors note that part of the challenge in understanding Sahel climate dynamics stems from the fact that aerosol forcing has overwhelmed the solar influence on the region. Several studies have attempted to use the identified links between solar cycles and monsoon variability to predict Sahel rainfall. Sheen et al. (2017) identify skill in predicting Sahel rainfall on inter-annual and decadal time scales, with similar results from Martin and Thorncroft (2014). The latter authors find CMIP5 hindcasts to have predictive skill beyond the persistence of the previous decade. However, an issue noted by Berntell et al. (2018) represents the fact that certain reanalysis products display a dipole pattern opposite to that found in observations, potentially undermining efforts to detect solar influences on climate.

4.3. Economic Impacts on Agricultural Markets

From the Maunder Minimum, historical evidence indicates that harvest failures increased, the length of growing seasons decreased and grain prices rose (Ljungqvist et al.).Pustilnik and Din (2004) detected quasi-periodic price bursts in grain data from medieval England to the modern United States, particularly during low solar activity. Moore's (1914) "generating cycles" concept and subsequent spectral analyses confirm that agricultural price series contain periodicities at timescales consistent with solar forcing, though attribution remains challenging (Franke, 2004).

For contemporary Pakistan, these considerations have great relevance. Pakistan’s wheat and cotton markets are part of national and international commodity chains, and the food price surge initiated in the country in August 2022 the largest since 1975 has already demonstrated how susceptible the national economy is to supply shocks (Sohail et al., 2023). Solar cycles influencing supply chains in more than one producing center will create greater fluctuations for Pakistan's wheat and cotton markets during particular solar cycles, affecting the population in varying degrees depending on their spending on food.

4.4. Pakistan's Agricultural Vulnerability

Pakistan's economy features the agricultural sector, which comprises 20-25 percent of the national Gross Domestic Product (GDP) and provides employment to about 45 percent of the population (Basharat, 2019 ; Janjua et al., 2021).

The Indus Basin produces the largest contiguous irrigation system in the world, but the country only stores 150 cubic meters of water per person compared to 5,000 cubic meters or more in developed countries such as the USA. For Pakistan, the agricultural sector is vulnerable to annual fluctuations in water resources, which may be influenced by solar cycles through monsoon dynamics and glacial meltwater. On the occasion of the 2022 floods, 45 percent of Pakistan's cropland was flooded, and 727,000 cattle died, causing a food shortage and price shock (Sohail et al., 2023).

According to remote sensing analysis, 78 percent of Sindh's cultivable land was affected by floods, with 98 percent of rice areas and 86 percent of wheat areas (Sarwar et al., 2024). More than twenty major floods have occurred since Pakistan's independence, causing $39 billion in damage.

Moreover, Pakistan is the third-largest groundwater user in the world, with 1.2 million tubewells providing water for agricultural crops (Qureshi, 2020). About 60 billion cubic meters of groundwater are extracted annually in Pakistan, but groundwater levels are declining at a rate of 0.5-3 feet per year (Zakir-Hassan et al., 2022).

Climate change and the progressive melting of glaciers threaten to reduce water resources in the future, affecting Pakistan's agriculture sector (Khan et al., 2025). Agricultural extension services in Pakistan face challenges as the proportion of farmers contacting extension agents has decreased significantly (Jan et al., 2008). Alzhrani et al. (2023) indicated that public extension services are more likely to be preferred by large farmers compared to small farmers.

4.5. Socioeconomic Mediating Factors

Socio-economic conditions play a key role in translating between climate variability and agricultural outcomes. Land tenure security becomes a precondition for the adoption of long-term adaptation measures, because the tenants-at-will are far less likely to take up such measures because of uncertain returns, while Faruqee (1999) noted that land tenure security enhances the responsiveness to incentives in Pakistan.The second critical difference concerns gender-differentiated vulnerability, women in agriculture are particularly vulnerable due to their limited access to land, credit, and extension, while Hidrobo et al. (2024) identified similar constraints. Credit constraints, in turn, emanate from both a lower supply of credit to women and the higher demand for credit on the part of women, which may be related to their constrained access to other assets. According to Balana et al. (2022), who studied the situation in Ethiopia and Tanzania, the demand-side limitations were, if anything, more significant compared to thesupply-side constraints, with women being constrained in both. The combined vulnerability stemming from multiple factors has a cumulative effect, according to the compound vulnerability framework: thus, a female smallholder farmer with limited access to tenure, credit, or extension would have a significantly higher level of vulnerability than one facing only one of these challenges. This implies that programs based on informing farmers about the possibilities of solar energy may be insufficient in the case of vulnerable groups, requiring more targeted interventions.

4.6. Pest and Disease Dynamics

Climate variability affects pest population dynamics, creating secondary pathways for solar-cycle influence. Mala et al. (2012) found Cameroonian farmers perceived increasing pest severity over fifteen years and adjusted cropping calendars accordingly. The desert locust presents the most dramatic case: Showler et al. (2022) documented the 2018–2021 episode devastating cotton, wheat, and maize across sixty Pakistani districts, while Liu et al. (2024) found over one-fifth of high-risk country pairs faced spatially synchronized locust risks modulated by ENSO.

Yu et al. (2009) detected periodicities of 2–10 years and 20–110 years in the Chinese locust records over the last millennium; the latter may be due to forcing from the solar cycle. Tang et al. (2023) projected future (climate change) conditions where the locust-free space currently uninhabitable would be suitable. Le and Nguyen (2022) found that pregnant women exposed to locusts experienced a reduction in anthropometric measurements among children with the most vulnerable children being adversely affected. This highlights the feasibility of early warning systems based on solar energy to reduce the loss of crops and associated intergenerational health effects.

4.7. Agricultural decision making under uncertainty

Research in behavioural economics shows that farmers are not all alike in how they react to climate information. It highlighted the importance of the prospect theory and its two tenets: loss aversion and probability weighting, in the understanding of climate risk responses. Climate information provision does not necessarily create the adaptive behavior, as behavioral preferences have systematic effects on risk management decisions. Hogan et al. (2011) identified the unique characteristics of adaptive capacity as psychosocial factors: social connectedness and information readiness. In Italy Ricart et al. (2024) identified four farmer profiles, highlighting again that a one-size-fits-all approach to information delivery will not be effective.

In the case of Pakistan, Ahmad et al. (2022) found that paradoxically large farm household heads were less likely to be adopting risk measures whereas educated male farmers were more likely to be so, suggesting social heterogeneity. Hellin et al (2021) also argue for transformative change to adapt to root causes of vulnerability because adaptation strategies relying only on technological solutions and without taking into account socio-economic context are not enough. It was recommended that the application of solar-cycle predictions and the predictions' effects should be based upon not only scientific validity, but also socio-psychological acceptance, social organization and institutionalization.

4.8. Institutional and Policy Frameworks

Institutional frameworks determine whether solar-cycle information translates into actionable guidance. Agricultural insurance represents a promising mechanism: Shirsath et al. (2019) presented weather-based crop insurance design methodology that could incorporate solar-cycle phase information. Liu et al. (2008) demonstrated ENSO-phase-dependent insurance optimization, providing a template for solar-cycle-informed products. Jangle et al. (2016) developed a multi-parameter "Climate Cost of Cultivation" index improving payout-yield correlation by a factor of Gender-differentiated barriers must be addressed: Born et al. (2019) found dedicated intention is required to ensure insurance benefits reach women.

Digital infrastructure offers transformative delivery channels. According to Khan et al. (2019), 91 percent of farmers in Punjab own mobile phones, while according to Caine et al. (2018), the PICSA approach to climate information delivery has been successfully piloted with considerable potential for scaling up. Nevertheless, the same study by Krell et al. (2021) revealed that only 25 percent of Kenyan small-scale farmers used mobile phones as a source of information on agriculture. It should also be noted that water governance reforms are at the center of attention in many countries. Indeed, according to Muzammil et al. (2020), it is possible to reduce water use by 35 percent by optimizing the crop patterns, while according to Mekonnen et al. (2018), the main reason why farmers resort to groundwater is the highly variable surface water deliveries. Spielman et al. (2017) noted that agriculture employs nearly half Pakistan's labor force yet receives insufficient policy attention.

5. Critical Discussion

5.1. Areas of Agreement

Four themes have emerged as common across the literature. First, while the mechanisms involved are not fully understood, solar magnetic cycles and in particular the 22 year Hale cycle are real phenomena which directly impact climate processes on Earth, and have been observed through a number of methods including solar physics, cosmogenic isotopes, and climate proxies. Second, solar forcing has differential impacts on patterns of precipitation in key agricultural regions such as the Asian monsoon and the African Sahel, which are mediated via teleconnection mechanisms such as ENSO, the North Atlantic Oscillation, and the Indian Ocean Dipole, rather than direct insolation. Third, social mediation of climate change is a widespread phenomenon tenure, gender, credit, extension, and governance interact with climate information to determine response. Fourth, Pakistan has multiple factors which act together to produce a climate risk premium a combination of monsoon and glacier meltwater sources, high risk of extreme weather events, water resource mismanagement, and institutional challenges.

5.2. Areas of Disagreement and Uncertainty

There are several challenges worth noting. First, the role of solar climate signals relative to internal variability and anthropogenic forcing is unclear, as some studies identify a discernible solar signal, while others do not. Second, with non-stationary relationships between solar activity and climate outcomes, there is a risk that past associations may be insufficient indicators for future trends. Third, the relative influence of different teleconnection pathways is poorly understood; some studies emphasize the role of ENSO while others highlight the North Atlantic or Indian Ocean. Fourth, few studies have adopted a causal identification strategy to investigate solar effects on agriculture outcomes.

5.3. Methodological Assessment

The literature reviewed takes various approaches, with some having advantages and disadvantages. Time series methods can be used to detect periodicities, but they are not very powerful for establishing causality. Climate models can attribute the influence of the sun, but are limited by the resolution and limitations of teleconnection parameterization. The econometric approach can be used to estimate the historical connection; however it has theoretical limitations and has the potential of causing endogeneity problems. The strengths of remote sensing are in its spatial coverage, while its limitations are the temporal scope—only during the satellite era. Ethnographic methods have a lot of information but are not statistically powerful. New methodologies have been developed that could use the haltering of the Hale cycle as an exogenous event to identify causes of climate variability is an important area of climate-teleconnection research.

6. Research Gaps

The critical synthesis reveals 12 research gaps that limit scientific understanding and the ability to practically implement agriculture based on solar cycles.

Table 2: Summary of Identified Research Gaps

Category	Specific Gap	Priority
Conceptual	No integrated theoretical framework spans the full solar-to-livelihood causal chain	High
Conceptual	Uncertainty whether Hale (22-year) or Schwabe (11-year) cycle is relevant for forecasting	High
Empirical	No causal identification of solar-cycle effects on Pakistani agricultural outcomes	High

Category	Specific Gap	Priority
Empirical	Limited evidence on solar-cycle modulation of groundwater recharge and glacier melt	High
Empirical	Gender-differentiated impacts of solar-cycle variability unstudied	Medium
Methodological	Absence of experimental evaluations of solar-informed agricultural advisories	High
Methodological	Lack of standardized solar activity indices for agricultural applications	Medium
Methodological	Insufficient integration of solar-cycle information with seasonal forecast systems	High
Theoretical	Limited understanding of farmer processing of multi-year cyclical climate information	Medium
Geographical	Sparse evidence from South America, Southeast Asia, and Central Asia	Medium
Policy	No operational example of solar-cycle-informed extension, insurance, or water management	High
Policy	No cost-benefit analysis comparing solar-informed adaptation with alternative strategies	Medium

7. Future Research Agenda

Four areas of research are suggested to fill the gaps identified.

7.1. Solar Energy and Power in the Developing World.

Operationalize sunspot based approaches to terminator based approaches to agricultural forecasting cycle frameworks; develop standardized solar activity indices systematically weighting sunspot/TSI based indices with other solar activity parameters that have been shown to play a role in the targets (UV, solar wind, cosmic rays, etc).

7.2 Strengthening Empirical Evidence

Conduct causal identification analysis using instrumental variables or natural experiment designs to find out the impact of solar cycle on agriculture. Conduct long-term (prospective) climate studies of climate variables affected by the sun and productivity and livelihood data on several Hale cycles. Carry out gender specific, impact studies and cross-regional comparison studies in under-represented regions.

7.3. Developing Decision-Support Tools

Combine Solar Cycle information into existing seasonal forecast systems, to produce multi-timescale products. Apply participatory design processes which involve farmers, especially women and the tenants, in the development of understandable and usable forecast products. Identify communication modalities that maximize adaptive responses by using experiments with behavior.

7.4. Evaluating Institutional Innovations

Describe and test water management, extension and insurance pilots, rigorously, on the basis of solar cycle. Carry out cost/benefit analyses of investments in solar energy rather than other methods of risk management. Explore scaling pathways to determine the institutional conditions and resource needs at the national level for scaling up programmes.

Table 3: Proposed Future Research Agenda

Priority	Research Area	Timeline
High	Hale cycle-based agricultural forecasting frameworks	2 to 3 years
High	Causal identification of solar-cycle effects on Pakistani agriculture	3 to 5 years
High	Integration of solar-cycle with seasonal forecast systems	2 to 4 years
High	Rigorous evaluation of solar-informed agricultural pilots	5 to 7 years
Medium	Gender-differentiated impact assessment	3 to 4 years
Medium	Cross-regional comparative studies	4 to 6 years

Priority	Research Area	Timeline
Medium	Behavioral experiments on cyclical climate information processing	2 to 3 years
Medium	Cost-benefit analysis of solar-informed adaptation investments	4 to 5 years

8. Policy Implications

The evidence found has five policy implications for Pakistan and for all countries and areas like Pakistan.

8.1. Incorporate into Agricultural Advisory Systems Solar-Cycle Forecasts.

Extension and agro-meteorological services in Pakistan should use Hale and Schwabe cycle indicators in their crop advisory bulletins. This should however go hand in hand with extension reform; as it is not reaching the smallholders and women (Jan et al., 2008; Alzahrani et al., 2023). A Solar education system should be a transformed system and transform from passive office based to participatory field based approaches.

In this section, we will reform index insurance by incorporating solar-cycle parameters. In this section, we reform index insurance with solar-cycle parameters.

Insurers' regulators should consider using solar-cycle phase as another index variable, in addition to Liu et al.'s (2008) ENSO-phase adjustment methodology. A template can be found in the multi-parameter "Climate Cost of Cultivation" index (Jangle et al., 2016). Born et al. (2019) found gender differentiated barriers which need to be overcome to achieve equal access.

8.2. Invest in Water Governance Reform

Water governance should incorporate multi-year hydrological forecasts informed by solar activity. Rational electricity subsidy reform and strengthened institutional enforcement are needed to address accelerating groundwater depletion (Zakir-Hassan et al., 2022). Water-saving strategies including optimal cropping patterns (Muzammil et al., 2020) should incorporate solar-cycle-informed water availability projections.

8.3. Develop Gender-Responsive Climate Information Systems

Solar-informed services must explicitly address gender disparities in land, credit, technology, and extension access. Targeted interventions including women-focused farmer groups and gender-sensitive mobile platforms are essential (Hidrobo et al., 2024; Balana et al., 2022).

8.4. Establish Cross-Agency Coordination

An inter-ministerial platform spanning the Pakistan Meteorological Department, Ministry of Food Security, provincial agriculture departments, and universities should coordinate solar science translation into policy. This would bridge the institutional fragmentation preventing climate information from reaching farmers (Spielman et al., 2017).

9. Conclusion

This review traced Sunspot theory from its early consideration based on Herschel's observations to modern understanding related to the Hale cycle. Solar-cycle variations influence the amount of precipitation and temperature, which in turn affect various agricultural regions. These effects are transmitted to crops, pests, and finally, to the market and farm settlement life. The connection to these elements is made via many links, which means the impact may vary depending on the land ownership relations, gender, access to credit, extension, and other factors. These are critical components for vulnerable groups of the population, affecting their adaptive capacity to climate change and food security. Integrating solar-cycle information into agricultural decision-making is not a panacea. Solar-climate relationships are regionally specific, temporally non-stationary, and modest compared with greenhouse gas forcing. Yet the quasi-periodic nature of solar variability, its partial predictability, and its documented modulation of monsoon dynamics justify inclusion in climate information portfolios. The path forward requires parallel investment in solar-climate teleconnection research, institutional reform, participatory information design, and gender-responsive delivery systems. Sunspot theory has achieved scientific maturity; the challenge now is embedding that knowledge in decision-making systems capable of translating heliophysics into rural development outcomes.

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