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A Systematic Review on Water Use Efficiency (WUE) and Soil Moisture Dynamics in Wheat-Based Agroforestry Systems

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***Abstract*— *Globally, wheat productivity and sustainable agricultural development are being significantly impacted by water constraint, decreasing soil moisture availability, and rising climate unpredictability. The potential of wheat-based agroforestry systems to increase soil moisture conservation, maximize water use efficiency (WUE), control evapotranspiration, and promote ecosystem sustainability has made them a promising climate-resilient strategy. In addition to summarizing the impact of tree-crop interactions, water management techniques, and new measurement tools, this systematic review assesses the body of research on WUE and soil moisture dynamics in wheat-based agroforestry systems. The review was carried out using literature gathered from major scientific databases, such as Science Direct, Scopus, Springer Link, and Google Scholar, covering studies published between 1960 to 2025, in accordance with the preferred reporting items for systematic reviews and meta-analysis (PRISMA) framework. To find patterns in soil moisture behavior, evapotranspiration processes, agroforestry treatments, and WUE improvement techniques, publications were searched and evaluated. The results showed that through canopy modification, litter deposition, increased soil organic matter, and microclimatic regulation, agroforestry systems have a significant impact on soil moisture distribution, infiltration characteristics, runoff regulation, root-zone water availability, and crop water productivity. While excessive competition for water, nutrients, and light negatively impacted wheat growth and production, well-managed tree-crop combinations enhanced WUE and soil moisture retention. The assessment also noted contemporary developments in machine learning and remote sensing technologies, as well as traditional field-based methods and process-based models like CROPWAT.*

Keywords*— *irrigation management, soil moisture dynamics, water use efficiency, wheat-based agroforestry

I. INTRODUCTION

One of today's most critical issues is providing a consistent supply of safe and nutritious food for a growing global population while also protecting the environment and reducing climate change. Agriculture is the major contributor to greenhouse gas emissions and world's largest consumer of land and water resources [1]. Particularly in emerging nations, agriculture continues to be a vital industry for maintaining livelihoods, guaranteeing food security, and promoting economic growth. However, a complex interaction of environmental, socioeconomic, and climatic elements is posing a growing difficulty [2]. One of the biggest issues confronting humanity in the upcoming decades is water scarcity. Conservation agriculture techniques increase soil moisture availability, particularly in low-rainfall situations, and may help sustain crop productivity in a changing climate [3]. The method of agriculture known as conservation agriculture, which aims to reduce environmental harm and soil disturbance, is being widely pushed globally. A key element of conservation agriculture is conservation tillage, which is thought to improve soil health through plant growth, land development, and environmental preservation. A sustainable farming method that seeks to improve soil health, preserve water, and lessen environmental deterioration is conservation tillage. It entails controlling crop residues on the soil's surface and reducing soil disturbance during crop planting [4]. Conservation tillage helps in maintaining soil moisture by reducing evaporation [5]. A recent meta-analysis found that using conservation agriculture methods in south asia increased productivity, water consumption efficiency, and net profit by 5.8%, 12.6%, and 25.9%, respectively, while reducing the potential for global warming by 12–33% [6].

Ecosystems, life, and social development all depend on water. However, over 1.2 billion people globally still lack regular access to clean water, highlighting the fact that it is acknowledged as a fundamental human right. Growing freshwater stress is a result of increased water demand brought on by population growth, urbanization, industrial expansion, intensive agriculture, and climate unpredictability in many areas, including India. The world economic forum often lists water shortages as one of the biggest challenges to the world's economy and society. According to projections, the world's water demand would rise by 55% from 2000 levels by 2050 due to changes in consumption patterns, pollution, and the need for more irrigation [7][8]. Understanding and resolving the interaction between such compound occurrences and water systems is essential for resilience-building and sustainable resource planning as climatic variability increases. Population growth is a second important element that increases freshwater demand in the residential, agricultural, and industrial sectors. According to [9], the world's population is predicted to reach 8.5 billion by 2030 and surpass 9.7 billion by 2050. This would result in a 50% rise in food consumption, which will necessitate 40–50% more water for agriculture and 50–70% more water for municipal and industrial use [8]. Furthermore, CO_2 emissions and the human population are strongly correlated. A billion more people on the planet results in 1.4 Pg more CO_2 emissions from burning fossil fuels (1 Pg = 1015, g = 1 Gt) [10]. Developing irrigation techniques that use the least amount of water is becoming more important due to global water problems and irrigation expenses [11].

Changes in land use and land cover, which operate on a temporal scale in physical and biological features, are indicative of landscape dynamics. Changes in the structure of the landscape are caused by both natural and anthropogenic factors [12]. Monitoring spatial patterns of changing land use and land cover (LULC) [7] or obtaining detailed information about land use and land cover change is essential for making decisions that will effectively accomplish the goal of sustainable development [13]. Additionally, dry soil salinity has a major impact on agricultural output [14], making it a major challenge for the agricultural sector to feed the world's growing population [15][16].

Researchers, governments, and farmers are all becoming increasingly concerned about the major issues that climate change presents to agricultural systems around the world [17]. Extreme weather events including heat waves, floods, and droughts are becoming more frequent and severe, endangering livestock, agricultural output, pest and disease prevalence, and soil fertility [18]. Due mostly to climate change, the majority of nations in the globe are dealing with the issue of yield stagnation and decline, particularly in cereals. Significant production reductions result from shifting climatic circumstances, such as high temperatures, coinciding with wheat's grain-filling stage [19]. Adopting weather, water, carbon smart agriculture, and nutrient; which includes planting date changes, crop diversification, better irrigation techniques, drought-tolerant crop varieties, and agroforestry practices - is the main focus of the potential adaptive strategies that agricultural researchers are currently investigating [20][21].

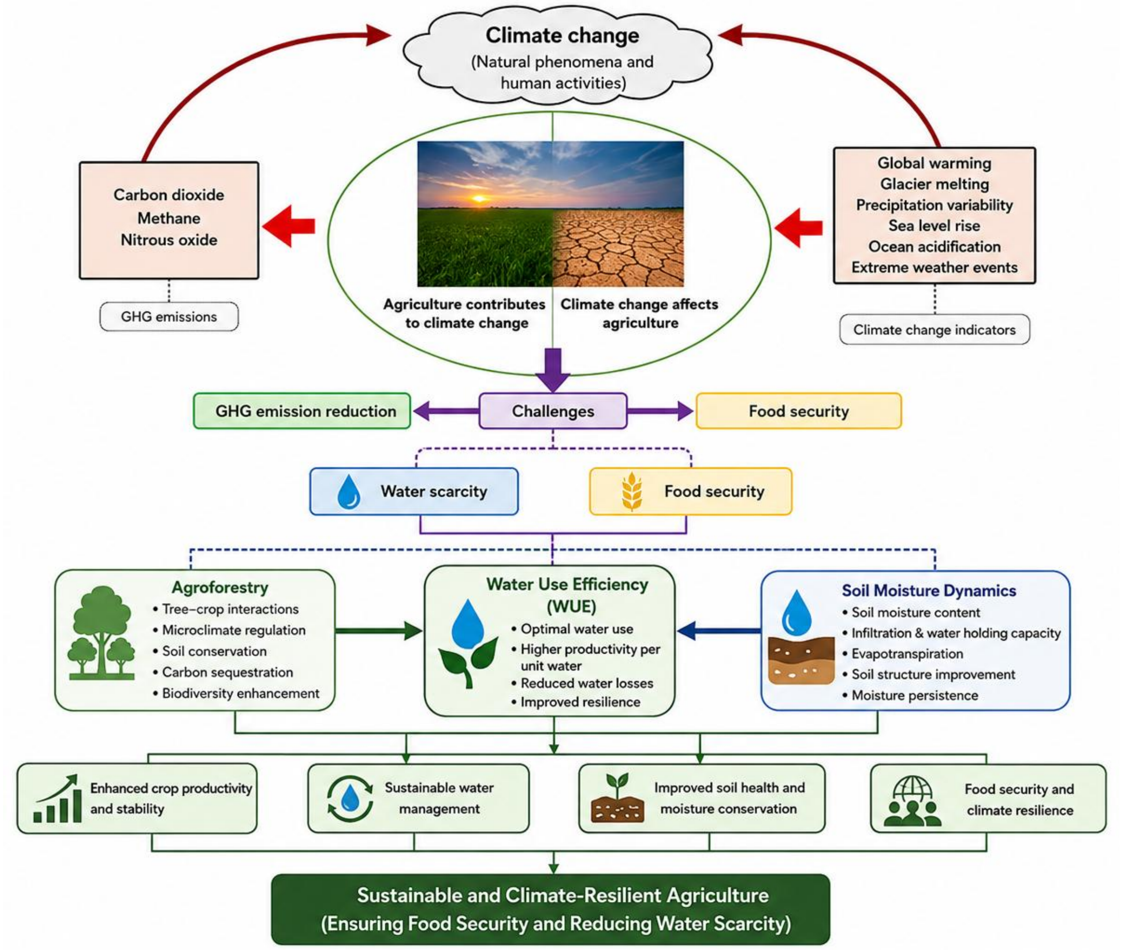

Fig. 1: Conceptual framework illustrating the linkage among climate change, agriculture and key challenges (water scarcity and food security) and the role of agroforestry, water use efficiency (WUE) and soil moisture dynamics in building sustainable and climate-resilient agriculture.

While over 83% of current worldwide adaptation efforts indicate little potential to reduce risks, investments in sustainable agriculture have a tremendous potential to alleviate food insecurity, according to the IPCC 6th Assessment Report [22][23]. However, there is limited information on how effective these solutions will be as global warming continues [24]. Agroforestry and sustainable agricultural intensification are crucial tactics for guaranteeing food security. In addition to regulating the carbon and nitrogen cycles, forests are essential for maintaining a stable global temperature [25]. Additionally, the local and global climate are impacted by environmental changes in forests [20]. In agroforestry systems, the deep roots of trees increase the soil's capacity for water infiltration and storage, lowering surface runoff and soil erosion by up to 90%, lowering soil nitrogen and phosphorus residues by up to 100%, and guaranteeing more water availability during dry spells [11]. Despite the social and economic potential of these approaches, they frequently encounter institutional and technological obstacles. High input costs - such as those of labor, capital, and land remain significant challenges. However, it has been demonstrated that these adaptation choices can lessen economic and social inequality. Co-benefits and more effective and economical climate action can be achieved by coordinating climate adaptation with the sustainable development goals (SDGs) [24][26].

To alleviate these challenges, sustainable soil and water resource management practices are increasingly critical for preserving farm productivity, increasing irrigation efficacy, and improving climate resilience. Examples of soil and moisture conservation strategies that have demonstrated positive effects on soil health, food security [9], carbon sequestration, and water retention include cover crops, crop rotation, conservation tillage, agroforestry systems, and improved irrigation techniques. These strategies are crucial tools for sustainable agriculture [22].

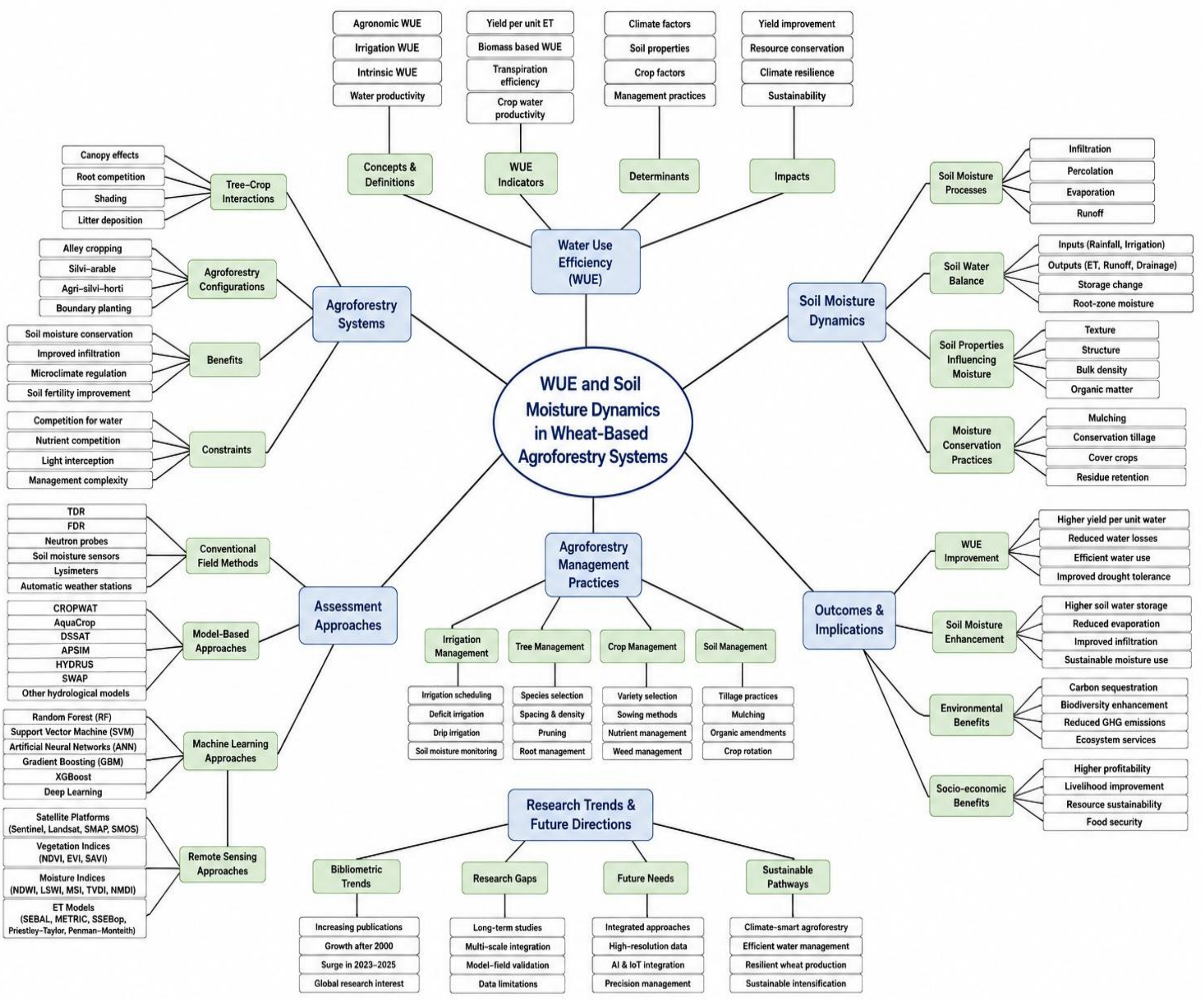

Fig. 2: Conceptual aggregation framework of water use efficiency and soil moisture dynamics for wheat-based agroforestry systems including field methods, models, remote sensing, and machine learning approaches

II. METHODOLOGY

To critically assess published research on soil moisture dynamics and water use efficiency (WUE) in wheat-based agroforestry systems, a methodical and evidence-based literature review approach was used. To guarantee methodological transparency, reproducibility, and scientific rigor throughout the literature identification, screening, eligibility assessment, and inclusion processes, the review framework was created in compliance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Four globally renowned scientific databases—Science Direct, Scopus, Google Scholar, and Springer Link—were used to do a thorough bibliographic search. In order to capture both fundamental and modern developments in agroforestry, soil hydrology, irrigation management, and agricultural water productivity, the literature retrieval procedure encompassed publications from 1960 to 2025.

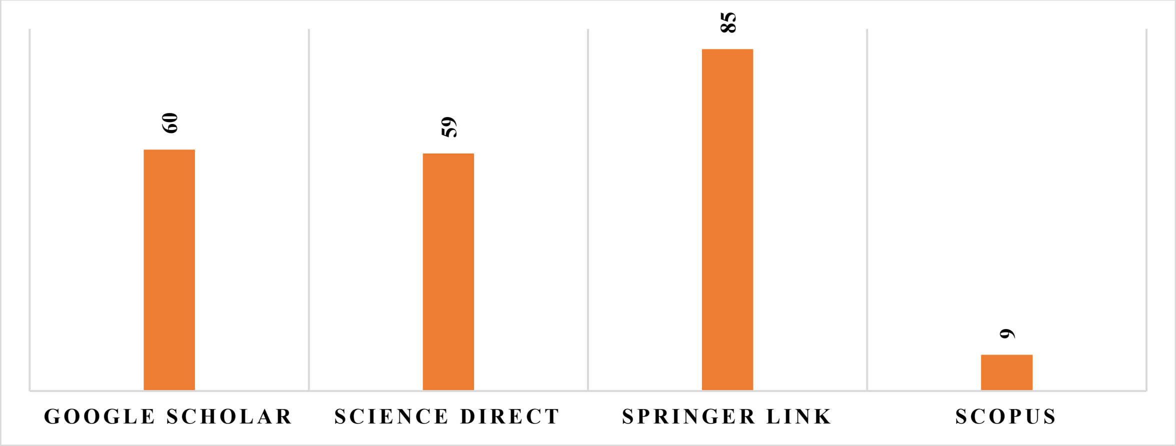

Fig. 3: The database-wise distribution of identified studies included

After eliminating the same publications (the same publication from two or more databases), a total of 213 records were first found during the primary database search.

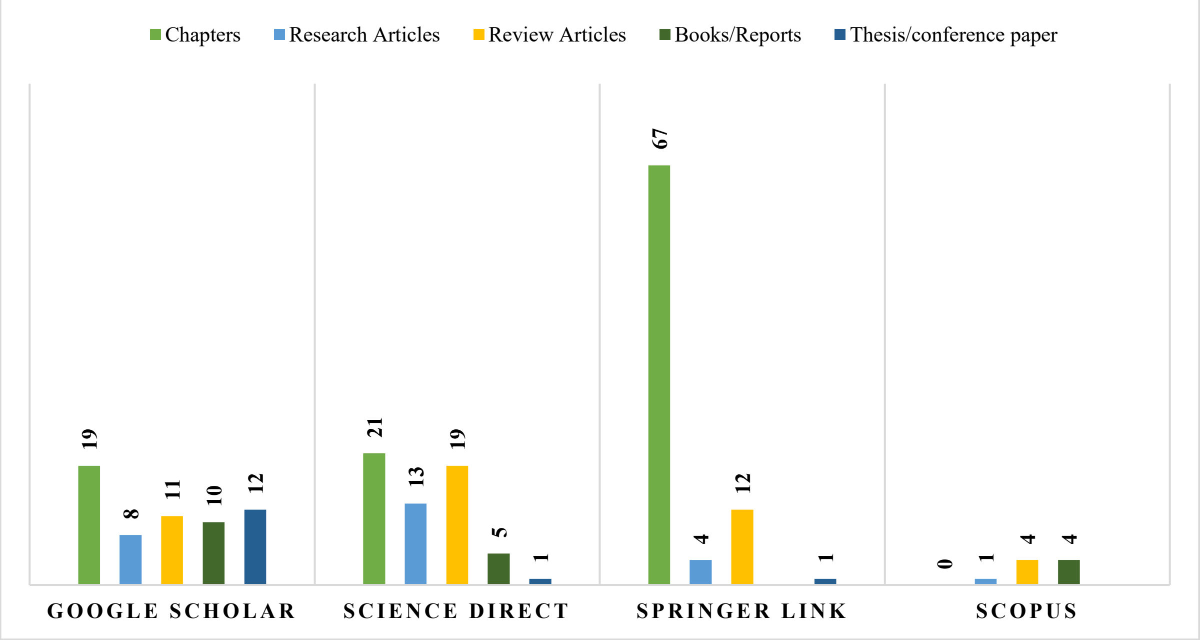

Fig. 4: Distribution of Literature Sources Retrieved from Different Scientific Databases

From Fig. 3, Bibliometric analysis of the selected literature revealed that investigations on water use efficiency and soil moisture dynamics in wheat agroforestry systems were sparse before 2000, indicating limited scientific attention during the initial phase. However, research output increased progressively after 2000, suggesting enhanced interest in agroforestry-mediated water management strategies. The most significant growth in publications was observed during 2023–2025, with 2025 showing the highest contribution, followed by 2023 and 2024. This trend reflects the increasing global focus on sustainable water utilization, climate adaptation, precision irrigation, and soil moisture conservation in wheat-based agroforestry ecosystems.

To increase the retrieval efficiency of pertinent research, the search method used technical keywords, Boolean operators, and controlled vocabulary concepts. Water use efficiency, soil moisture dynamics, wheat cultivation, wheat-based agroforestry, agroforestry systems, soil water conservation, evapotranspiration, irrigation management, crop water productivity, sustainable agriculture, soil moisture monitoring, and climate resilience were among the main search terms. Boolean operators like "AND," "OR," and "NOT" were methodically incorporated to enhance the specificity of the retrieved literature and refine the search results.

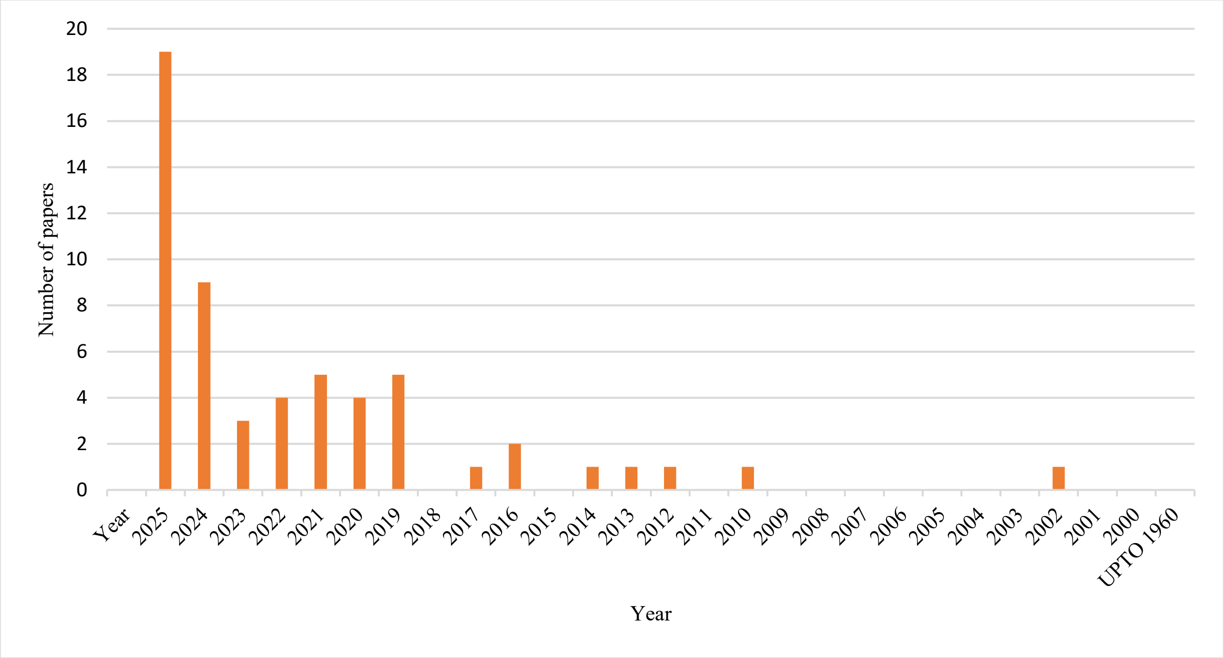

Fig. 5: Year wise publication trend for science direct database (from 1960 to 2025)

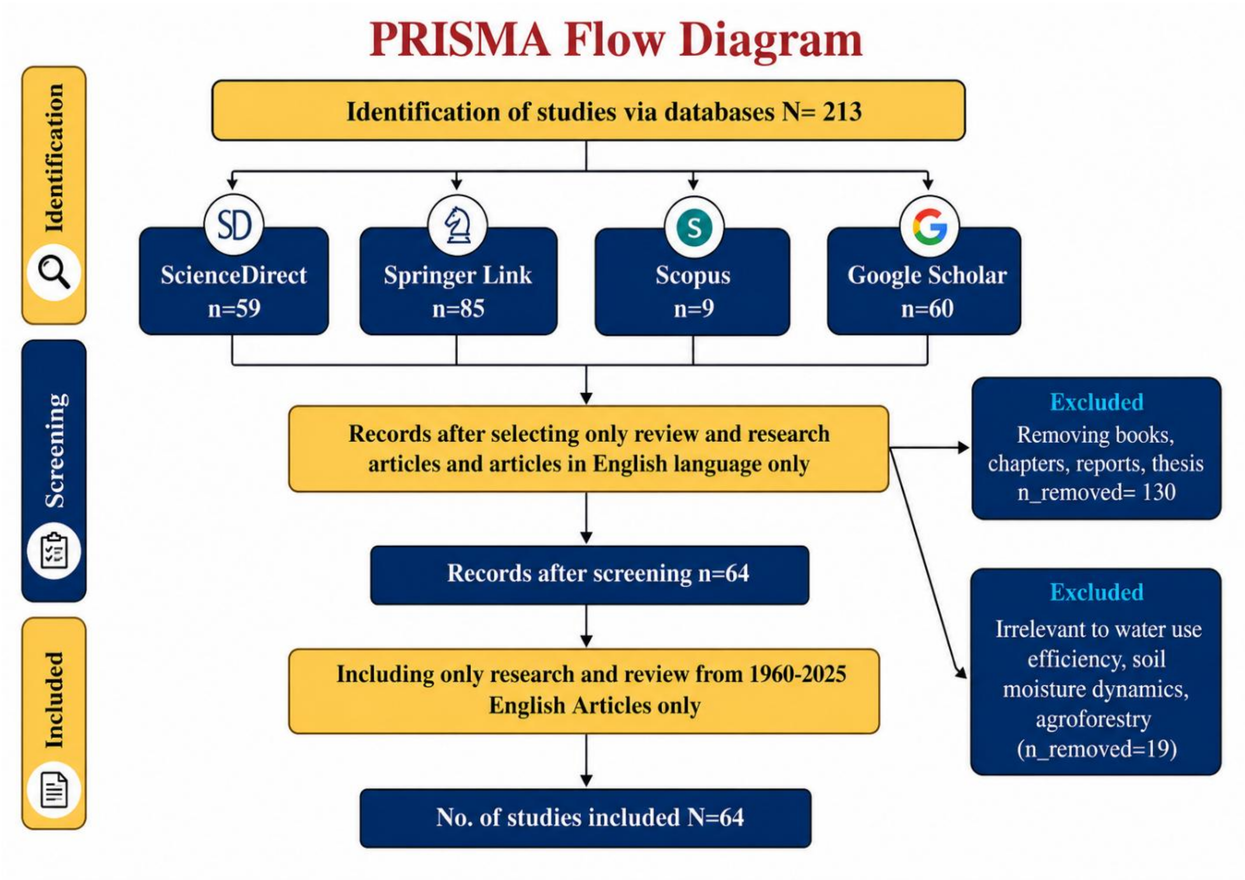

Fig. 6: This PRISMA flow diagram shows how studies are chosen for a systematic review.

A multi-phase screening procedure was applied to the collected records. Books, book chapters, reports, conference proceedings, dissertations, and non-English publications were among the non-research elements that were initially removed from the dataset. 130 records were eliminated as a consequence of this initial screening. The remaining publications were then screened for scientific value in relation to the review objectives using the title, abstract, and full text. Studies examining soil moisture behavior under agroforestry systems, water use efficiency in wheat cultivation, the effects of tree-crop interactions on soil hydrology, irrigation scheduling and water conservation techniques, and sustainable resource-use management in semi-arid and arid agroecosystems were given special attention. Nineteen studies were eliminated during the eligibility assessment phase because they were not sufficiently relevant to agroforestry-based wheat production systems, soil moisture dynamics, or water use efficiency.

Final inclusion was limited to peer-reviewed journal articles and review papers published in English between 1960 and 2025. Studies that offered quantitative or qualitative data on crop water productivity and irrigation efficiency, soil moisture conservation and hydrological processes, wheat production under agroforestry or integrated farming systems, and climate-resilient agricultural water management techniques were chosen.

The qualitative synthesis contained 64 studies in total after the methodical screening and eligibility evaluation processes. These selected research formed the scientific basis for evaluating the connections among agroforestry systems, soil moisture dynamics, and water usage efficiency in wheat farming. The compiled literature offers important insights into root-zone moisture dynamics, irrigation optimization, evapotranspiration regulation, soil water retention mechanisms, and sustainable agroecosystem management techniques under various edaphic and climatic circumstances. With regard to sustainable water management in wheat-based agroforestry systems under rising climatic variability and water scarcity circumstances, the integrated analysis made it possible to identify current research trends, methodological gaps, and future research goals.

III. RESULTS AND DISCUSSION

The average wheat yield in Northern India was 3.0 Mg ha^{-1}, but the potential yield was 7.5 Mg ha^{-1}, suggesting the biggest yield difference among the regions considered. With a potential production of 5.5 Mg ha^{-1} and an average yield of 4.1 Mg ha^{-1}, Punjab demonstrated substantially higher productivity, while there is still room for improvement. The average and prospective yields in Haryana were 3.8 Mg ha^{-1} and 4.0 Mg ha^{-1}, respectively, indicating a reduced yield gap and rather efficient production circumstances [10]. Wheat grain yields in agri-silvi-horticultural systems varied from 2.34 to 3.13 t ha^{-1} under tree-based systems and from 4.07 to 4.08 t ha^{-1} under sole cropping circumstances. The khejri + guava + wheat system yielded the most wheat (3.01–3.13 t ha^{-1}) out of all the combinations, suggesting that wheat is more compatible with greater canopy spacing and less competition. On the other hand, systems with more intense shading demonstrated comparatively poorer output [27]. According to studies conducted in Himalayan agri-horticultural systems, wheat cultivated with grewia + almond combinations outperformed other tree associations. Crop yield beneath the tree crown was roughly 17–19% lower than locations outside the canopy effect, and wheat yield losses under tree canopies ranged from 18–28% when compared with open-field agriculture. However, the grewia + almond + wheat system had the best soil moisture conditions and the highest net economic return, indicating the promise of improved agroforestry arrangements for sustainable wheat production [28]. Wheat yields in poplar-based agroforestry systems were also lower than in open cultivation, where the open-field grain yield was about 3.55 t/ha. Additionally, agroforestry treatments shown decreased productivity because of shading effects, particularly in eucalyptus-based systems. Poplar-based systems, on the other hand, outperformed eucalyptus (yield = 1.56 t/ha) and maintained enhanced soil nutrient status, indicating their viability for wheat integration in north Indian agroforestry regions (yield = 3.24 t/ha) [29]. Pea-wheat intercropping was used across the world for forage and grain production. According to a study by [30], intercropping can be impacted by the availability of water as well as the choice of cultivar, which can have an impact on water use efficiency and the intercropping system's productivity. While the water use efficiency values were lower in 2006–07 and 2007–08, the yield and Et_a of the winter wheat irrigated plots were greater than those of the rainfed plots [31]. According to [32], irrigation practices have a significant impact on NDVI readings and have a high positive association with both grain yield and biomass output. improved root growth and soil moisture retention.

Table 1: The overview of agricultural methods' effects on soil & water conservation, as well as other parameters (for example, yield). The results are contrasted with traditional tillage and agrichemical use [1].

Practice	Soil Conservation	Water Conservation	Yield
cover/catch crops	Boost the soil structure, increase soil organic matter (SOM) and decrease soil erosion	Soil moisture conservation, increase in soil water capacity, improved water quality downstream	15% increase in wheat yield [33][34]
Agroforestry	Reduce soil erosion, improved soil structure, increase SOM	Agroforestry in arable farming systems [35], Conserves soil moisture and protect crops during high summers and fast blowing winds and storms.	The grain yield was higher in an agroforestry system, and sometimes depend upon spacing btw trees and other factors [36].
Intercropping	Maintain soil structure, balance nutrient in soil and also maintain SOM level [1].	But it don't increase water use efficiency	Higher overall yield of the intercropped Crops [37]. On the other hand, compared to a wheat-only crop, one study found that intercropping winter wheat with clover reduced wheat grain yield by 10–25%. [38].
Residue retention/Mulch	Efficient in reducing erosion (1.7 t/ha-y compared to 4.6 t/ha-y of soil loss) [33][34]	Soil moisture maintained [4], Lowering in evaporation from soil.	Enhancing yield of wheat (15% higher) [33]
Minimum tillage	Reduce soil erosion & nutrient loss [39]	Lowering moisture loss, water runoff & reduce sedimentation [40]	Yields are higher or equal to systems using the conventional tillage [41]
Crop Rotation	Reduces soil erosion, increases soil fertility, regulating soil nutrients & building soil structure [42]	Decreases pests and diseases. And increase in soil water capacity [43].	Grain yield was higher in the winter oilseed rape–winter wheat–winter wheat–winter barley crop rotation system (83.5 grain yield/ha) than in the later (72.9 grain yield/ha) [44]
No till/Direct seeding	Reduce soil erosion & nutrient loss [45].	Lowering moisture loss [32], water runoff and reduce sedimentation	Crop yields were higher when no-tillage was combined with weed management and fertilizer application rates of either 50% or 100% [46]

The conventional approach involves direct field measurements using instruments such as time domain reflectometry (TDR) [47], soil moisture sensors, frequency domain reflectometry (FDR) [48], neutron probes, and automatic weather stations (AWS) for monitoring soil moisture status, climatic parameters, crop growth characteristics, and evapotranspiration. These observations are subsequently utilized for WUE estimation based on crop yield [49]and actual evapotranspiration relationships [50] and for evaluating temporal and depth-wise soil moisture variations [51].

The model-based domain includes simulation tools such as CROPWAT [52], DSSAT, APSIM, SWAP, HYDRUS, and other hydrological models, which integrate climatic variables, soil properties, irrigation scheduling, crop coefficients [53], and agroforestry configurations to estimate evapotranspiration, irrigation water requirement, root-zone soil moisture, crop yield, and water productivity indices.

Machine learning approaches incorporate environmental variables, soil characteristics, remote sensing indices [13], crop parameters, and management information to develop predictive models using algorithms including random forest (RF) [54][55], support vector machine (SVM) [56], artificial neural network (ANN), gradient boosting machine (GBM), extreme gradient boosting (XGBoost) [57], and deep learning architectures. These methods enable prediction of soil moisture content, water use efficiency estimation, evapotranspiration modeling, yield forecasting, and sensitivity assessment under varying agroforestry scenarios.

Remote sensing-based approaches employ multispectral, thermal, and microwave datasets derived from platforms such as Sentinel-2, Landsat, Sentinel-1, SMAP, and SMOS. Spectral indices including NDVI [58][13], EVI , SAVI, NDMI, MSI, and land surface temperature (LST), together with evapotranspiration models such as SEBAL, METRIC, and Priestley–Taylor formulations, facilitate spatial and temporal assessment of water use efficiency and soil moisture dynamics across wheat agroforestry landscapes.

The integration of these approaches provides a comprehensive evaluation framework for improving water management strategies, enhancing resource-use efficiency, supporting climate resilience, and promoting sustainable productivity in wheat-based agroforestry systems.

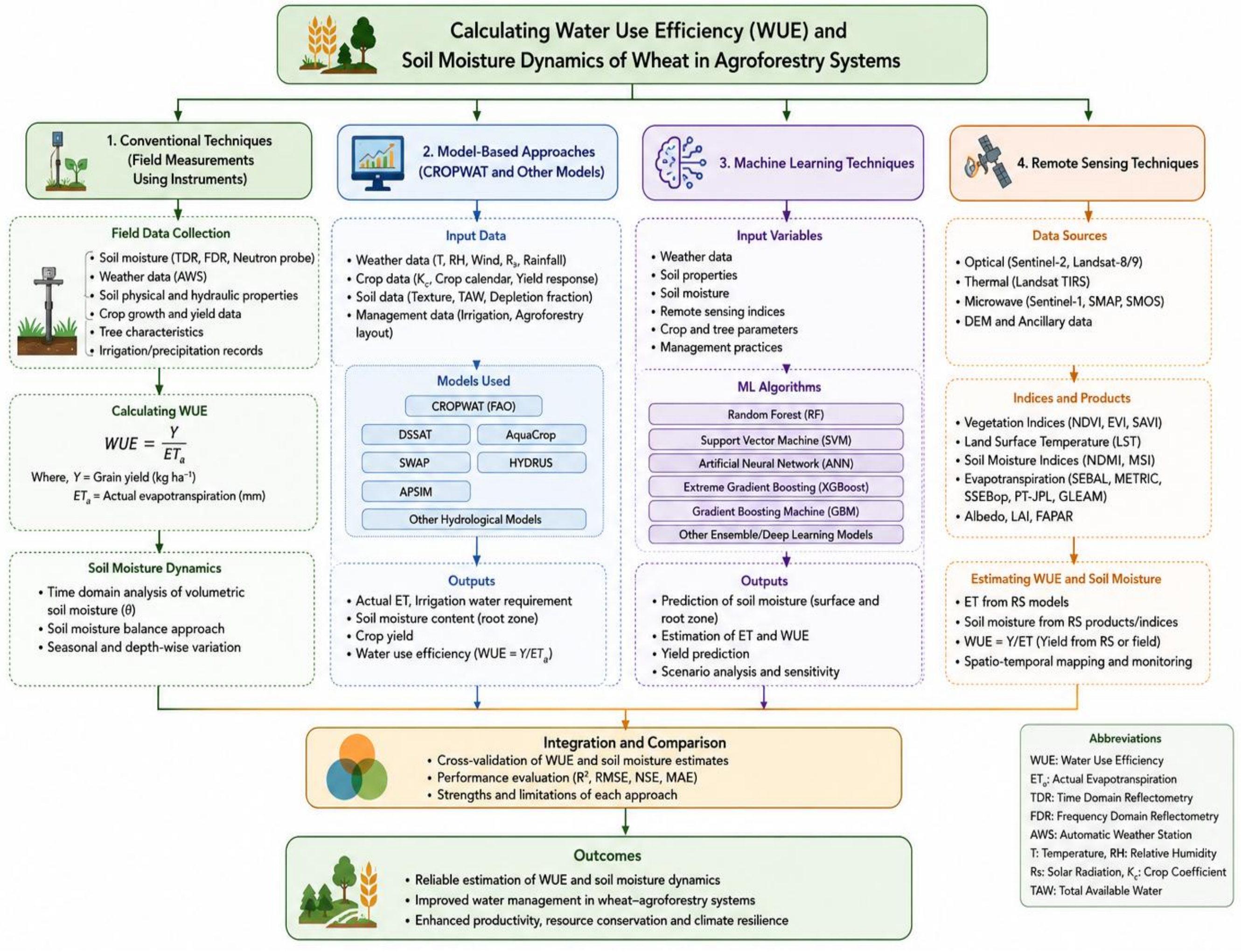

Fig. 7: Methodological framework for calculating water use efficiency (WUE) and soil moisture dynamics of wheat in agroforestry systems using (1) conventional field measurements with instruments, (2) model-based approach (CROPWAT and other models), (3) machine learning techniques, and (4) remote sensing techniques.

Table 2: Compilation of equations and indices used in water use efficiency, soil moisture monitoring, and evapotranspiration studies

Method Used	Formula Used	Representation	References
Water Use Efficiency Equations			
Agronomic water use efficiency	$WUE = \frac{Grain\ Yield}{Total\ Water\ Consumed}$	WUE = Water Use Efficiency	[59] [60] [50]
Irrigation water use efficiency (IWUE)	$IWUE = \frac{Y_i - Y_r}{I}$	Y_i = irrigated yield Y_r = rainfed yield I = irrigation depth	[59] [61]
Crop water productivity (CWP)	$CWP = \frac{Economic\ Yield\ or\ Biomass}{ET_a}$	ET_a = actual evapotranspiration	[62] [63]
Transpiration efficiency	$TE = \frac{B}{T}$	B = biomass T = transpiration	[64] [51]
Soil Moisture Dynamics Equations			
Gravimetric soil moisture	$SM_g = \frac{(W_w - W_d)}{W_d} * 100$	W_w = wet soil weight W_d = dry soil weight	[65] [66]
Volumetric soil moisture	$\theta_v = \theta_g * \rho_b$	θ_v = volumetric moisture θ_g = gravimetric moisture ρ_b = bulk density	[66] [47]
Soil water storage	$SWS = \theta_v * D$ $SWS = \sum(\theta_i * d_i)$	D = root zone depth	[67] [68]
Water balance	$P + I = ET + R + D + \Delta S$	P represents precipitation, I stands for irrigation, ET is evapotranspiration, R is runoff, D represents deep percolation, and ΔS is storage change	[69] [70]
Energy balance based soil moisture	$R_n = G + H + \lambda ET$	H = sensible heat $\lambda * ET$ = latent heat flux	[71]
Soil moisture depletion	$D_r = D_{r(i-1)} - (P - RO) - I - CR + ET + D_p$	D_r = root zone depletion RO = runoff CR = capillary rise D_p = percolation	[72]
Remote Sensing Soil Moisture Models			
Normalized difference water index (NDWI)	$NDWI = \frac{NIR - SWIR}{NIR + SWIR}$	NIR = Band 8 SWIR = Band 11 or 12	[73] [74]
Land surface water index (LSWI)	$LSWI = \frac{NIR - SWIR}{NIR + SWIR}$	NIR = Band 8	[58]

		SWIR = Band 11 or 12	[75] [76] [77]
Soil moisture index (SMI)	$SMI = \frac{LST_{max} - LST}{LST_{max} - LST_{min}}$	LST = land surface temperature $0 \leq SMI \leq 1$	[78] [79] [80]
Temperature vegetation dryness index (TVDI)	$TVDI = \frac{(T_s - T_{smin})}{(a + b(NDVI) - T_{smin})}$	T_s = surface temperature a, b = dry edge coefficients	[81] [82] [83]
Vegetation Indices Related to WUE and Soil Moisture			
Normalized difference vegetative index (NDVI)	$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$	NIR = Band 8 RED = Band 4	[84] [85] [13]
Soil adjusted vegetation index (SAVI)	$SAVI = \frac{(NIR - RED)(1 + L)}{NIR + RED + L}$	NIR = Band 8 RED = Band 4	[86] [87] [88]
Enhanced vegetation index (EVI)	$EVI = G\left(\frac{NIR - RED}{NIR + C_1RED - C_2BLUE + L}\right)$	NIR = Band 8 RED = 4 BLUE = 2	[89]
Moisture stress index (MSI)	$MSI = \frac{SWIR}{NIR}$	NIR = Band 8 SWIR = Band 11 or 12	[90]
Normalized multi-band drought index (NMDI)	$NMDI = \left(\frac{NIR - (SWIR_1 - SWIR_2)}{NIR + (SWIR_1 - SWIR_2)}\right)$	NIR = Band 8 SWIR = Band 11 or 12	[91] [92]
Evapotranspiration Equations			
FAO Penman-Monteith	$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T + 273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$ R_n = net radiation, G = soil heat flux, u_2 = wind speed, and $e_s - e_a$ = vapour pressure deficit $ET_c = K_c * ET_0$		[93] [94] [95] [96]
Hargreaves Equation	$ET_0 = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}R_a$ R_a = extraterrestrial radiation, T_{mean} = mean temperature, T_{min} = minimum temperature and T_{max} = maximum temperature		[97] [98]
Thornthwaite Equation	$ET = 16\left(\frac{10T}{I}\right)^a$ Heat Index: $I = \sum\left(\frac{T}{5}\right)^{1.514}$ $a = 6.75 * 10^{-7}I^3 - 7.71 * 10^{-5}I^2 + 1.79 * 10^{-2}I + 0.492$		[99] [100]

Blaney-Criddle Method	$ET_0 = p(0.46T + 8)$ p = daytime hour percentage and T = temperature **Crop ET:** $ET_c = K_c ET_0$ [101]	[102] [103] [104]
Priestley-Taylor Equations	$ET = \propto \frac{\Delta}{\Delta + \gamma} \frac{(R_n - G)}{\lambda}$ $\propto$ = priestley-taylor coefficient, λ = latent heat of vaporization, G = soil heat flux density and γ = psychrometric constant.	[105] [106] [107]

IV. CONCLUSION

This systematic review evaluated the existing literature on water use efficiency (WUE) and soil moisture dynamics in wheat-based agroforestry systems and highlighted their importance for sustainable water management under changing climatic conditions. The reviewed studies indicated that agroforestry practices considerably influence soil water availability, evapotranspiration, infiltration, root distribution, and crop water productivity through improved soil structure, litter deposition, microclimatic regulation, and reduced evaporative losses. These interactions contribute to enhanced soil moisture conservation and efficient utilization of available water resources in wheat production systems. The findings demonstrated that the performance of wheat under agroforestry conditions is largely controlled by tree species, spacing arrangements, root interactions, irrigation practices, climatic variability, and soil characteristics. Properly managed agroforestry systems can improve WUE by increasing infiltration, reducing runoff, optimizing soil water storage, and enhancing drought tolerance. However, unsuitable tree density and improper management may increase competition for water, light, and nutrients, resulting in reduced crop performance and lower water productivity.

The review further identified the major approaches used for assessment of WUE and soil moisture dynamics. Conventional field-based methods, including Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), neutron probes, soil moisture sensors, lysimeters, and automatic weather stations, remain important tools for direct monitoring of soil water status and environmental conditions. In addition, process-based and simulation models such as CROPWAT, DSSAT, APSIM, SWAP, and HYDRUS have been extensively used for estimating evapotranspiration, crop water requirements, irrigation scheduling, and soil moisture distribution. Recent advancements in remote sensing and geospatial techniques have significantly improved large-scale monitoring of WUE and soil moisture variability using vegetation and moisture indices such as NDVI, EVI, SAVI, NDWI, LSWI, MSI, TVDI, and NMDI. Similarly, energy balance approaches and evapotranspiration models including Penman–Monteith, Priestley–Taylor, and SEBAL have enhanced water assessment capabilities across agroforestry landscapes. Machine learning techniques such as Random Forest, Support Vector Machine, Artificial Neural Networks, and deep learning approaches also showed increasing applicability for prediction and modeling purposes.

Publication trends revealed increasing research activity after 2000, with substantial growth during recent years, particularly from 2023 to 2025, indicating rising global interest in climate adaptation, water conservation, and sustainable agricultural systems. Overall, wheat-based agroforestry systems provide significant opportunities for improving WUE, conserving soil moisture, enhancing climate resilience, and supporting sustainable food production under increasing water scarcity conditions.

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Informed Consent Statement:

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Not Applicable.

Author Contributions:

Amandeep Singh: Conception, organization, writing of this review paper, and approval of final manuscript.

Atish: Writing of review paper, editing, critical review, and approval of final manuscript.

Vijay Singh: Critical review, editing, and approval of final manuscript.

Beena Kumari: Supervision, critical review, editing, and approval of final manuscript.

Sandeep Arya: Review, editing, and approval of final manuscript.

Ankush Kamboj: Review, editing, and approval of final manuscript.

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