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Towards multiservice irrigation for an agroecological future

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Agroecology and water management knowledge spheres have long been disconnected. This paper advocates bridging this divide to boost sustainable food production. We stress that a paradigm shift is needed so that irrigation will no longer be viewed merely as a technical productivity support tool. A multiservice irrigation concept is proposed whereby irrigation is planned and applied to enhance ecosystem functions essential for sustainable food production. We end this Perspective paper by outlining six frontier research themes to put this concept into practice in the coming years.

The dawning awareness of human-induced impacts on our planet in the Anthropocene has led to rethinking the way our natural resources are used, especially with regard to food production. There is growing recognition of the value of multifunctional agriculture, especially in its diversified forms[1]—ensuring food production while enhancing biodiversity and safeguarding natural resources. In the water realm, *care* rather than *control* of resources and infrastructure is now being championed as water governance is considered from a new perspective[2]. But these ideas are as yet far from being transformed into grassroots applications at the global scale.

Agroecology (AE) and irrigation are both promoted as solutions to enhance food system sustainability. Key international reports argue that several vital issues such as producing nutritious food and combating biodiversity loss may be effectively addressed by AE due to its systemic and integrative nature[3–6]. Irrigation is also a high priority on many policy-planning and development agencies' agendas, as it is often perceived—by both managers and farmers—as a positive factor that helps ensure food security, rural employment and the development of local and national economies. Both AE and irrigation are put forward as a climate change adaptation measure[7–9].

This Perspective paper explores the interplay between AE and irrigation. A major disconnect prevails between these two fields, and few studies have probed their combined outcomes. This discipline divide has led to missed opportunities to contemplate and design irrigation systems able to enhance ecosystem functions and services and in turn foster sustainable food systems. The *multiservice irrigation* concept we propose addresses the need for a paradigm shift to align irrigation practices with agroecological goals. The target is twofold: (1) to boost the awareness of the scientific community (and beyond) on this knowledge divide, while suggesting research pathways to effectively address this issue, and (2) to outline a novel conceptual framework.

Current divide between agroecology and irrigation

A striking shortcoming noted in contemporary scientific literature is the scant dialogue between the AE and irrigation disciplines[10], as also noted in the siloing of other scientific discourses[11]. Irrigation is usually presented in a very expedious manner in studies on AE systems, i.e. viewed more as a farm feature than a potential AE asset. Otherwise, the discourse that mainly prevails in the irrigation knowledge sphere calls for enhanced irrigation efficiency and productivity—where irrigation is viewed as a technical streamlining option rather than a transformative tool aligned with ecological principles. Scientists have only recently begun to probe the potential compatibility between AE and innovative irrigation practices e.g[12–15]. There seems to be a quasi-absence of scientific studies focused on potential interlinkages between AE and irrigation.

Yet the joint goal of AE and irrigation science and practice is to build sustainable food systems. AE is geared towards designing entire food systems based on ecological rationales and holistic and systemic approaches. The concept has evolved to encompass fundamental issues related to current global climatic, ecological and food system crises, by integrating 'research, education, action and change [to bring] sustainability to all parts of the food system'[16]. The idea is to build locally relevant food systems that support diverse smallholder farmers and provide nutritious food to consumers through equitable, just and accessible markets[17]. Water resource management, particularly concerning irrigation, is a critical aspect of food production. Irrigation is often perceived as a farm subcomponent but actually has much broader implications[18] as it involves water sourcing, distribution and management. In fact, irrigation profoundly changes the way of farming as well as the prevailing local environment: it modifies the soil-plant-atmosphere continuum and related ecological processes, along with the structure, functioning and farm outputs; it transforms landscapes through channelling, storage and other hydroagricultural features such as terraces, trenches, irrigation networks or reservoirs; it profoundly affects the way societies are organized; and finally it is a major human activity that impacts

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many phenomena at the global scale[19,20]. Improvements in irrigation management have long been driven by the 'more crop per drop' leitmotif, with a quest to achieve high agricultural productivity and water-use efficiency. Scientists have called for a paradigm shift to build more sustainable irrigation systems, while underscoring the necessity to include production quality indicators[21], in addition to human and cultural values[2] in irrigation performance analyses.

The divide between these two research fields is not only noted in the scientific literature, as already pointed out. Irrigation and AE are based on different mindsets, policies and management strategies. There are clearcut differences in their narratives (mainstream vs alternative forms of agriculture), goals (efficiency and productivity vs health and farmers' livelihoods), approaches (technological vs holistic), scales of analysis (plot and irrigation system vs farm and food system), as well as stakeholders (from distinct associations, government ministries or research laboratories)[10,22]. These differences could explain the dichotomy outlined earlier. The cornerstone precepts and concepts also differ. AE complies with a set of well-established principles—encompassing agronomic and ecological features, while also having broader socioeconomic, political and cultural facets—to guide decision making, action and behaviour[23]. Contrary to the AE sphere, there has been less effort to develop a consistent set of principles to guide irrigation system initiatives. Yet both spheres strive to improve agricultural and food systems: regarding AE, Gliessman[17] proposed an analytical framework involving five successive transition levels to achieve sustainable food systems, while Perret and Payen[21] called for irrigation to be focused more on ecosystem services and nexus connexions. Being two facets of the same system, AE and irrigation should hence be jointly designed and managed.

Reconciling two separate realms through multiservice irrigation

Irrigation and AE interact at multiple food system levels. From the irrigation standpoint, crop growth is fundamentally fostered by irrigation through water-related soil-plant-atmosphere transfers and processes (e.g. photosynthesis, nutrient uptake, pest and disease outbreaks). In typical crop irrigation management scenarios, irrigation is optimized according to conventional indicators (increased production, reduced cost, improved water-use efficiency), in reference to the above-mentioned lowest level of transition towards agroecological systems. Regarding the AE stance, it may be argued that irrigation could be optimized according to other criteria and thereby be part of the second and third transformation levels[17] (substitution and redesign). For example, irrigation could foster crop diversification, notably via the integration of vegetables and trees within the system. However, the beneficial role that irrigation could play in agroecological systems is still far from being completely understood. Water management also needs to be taken into account at higher transition levels related to changes at the food system scale. Irrigated agriculture—which prevails on approximately 20% of global cultivated land and accounts for 70% of global water withdrawals[24]—produces 40% of the world's food[25]. Irrigation is needed for a wide range of crops, which in turn provide nutritious diversified diets for humans. The agroecological transition of these irrigated landscapes is just as necessary as it is under rainfed agricultural conditions. At these transformational levels, the development of alternative food networks to produce a broad range of foods at the local scale highly depends on the extent of available water resources. Finally, if AE is scaled up to emerge out of its current niche sector, improvements could be expected with regard to natural resources (e.g. soil health, water quality), but the quantitative impact on water resources remains uncertain.

In the light of these tight interactions, it is essential to go beyond the current juxtaposition of these knowledge and action spheres to be able to achieve their true integration. We suggest doing this by combining the frameworks and principles to which both comply (Fig. 1). Irrigation analysis frameworks, i.e. nexus thinking and ecosystem services, are also relevant for AE. Yet the AE field currently lacks reflection on how to achieve a balance between agroecological food systems and rational water/energy use since the irrigation practices are largely overlooked. Similarly, the higher sustainable transition levels outlined by Gliessman[17] are relevant to reflect on the agroecological potential of irrigation beyond simplistic efficiency and productivity targets. Agroecology complies with 13 principles geared towards food system transformation, while in the research arena irrigation complies with a more restricted set, yet seven principles seem to be shared (Table 1, bold lines and Fig. 1a, b bold). Innovations—especially technological—are often showcased in the irrigation sphere while often lacking amongst AE proponents. Technological innovation could also underpin the AE quest. Embedding other AE principles in irrigation system planning could help achieve the full range of ecosystem services provided by irrigation, and would shift the emphasis in favour of providing food not only in quantity but also in (nutritional) quality. To achieve this, we propose that multiservice irrigation could reconcile water management with AE (Fig. 1c). Multiservice irrigation can enable or enhance ecosystem processes and functions necessary for sustainable food production, rather than only supporting yield/biomass production. It is based on the interaction between the operational aspects of the irrigation system—including its configuration, control and dosages—and so-called agroecological practices, to enhance the ecological functions of the soil and plants and generate a range of ecosystem services (Fig. 2). It is necessary to redesign irrigation systems, including all of its components and governance structures, to be able to achieve multiservice irrigation for agroecological systems. Multiservice irrigation must also be reasoned and evaluated at different spatial scales to promote its wise use and not simply to justify the need for irrigation while overlooking the multiple disservices that irrigation often currently produces. The consolidated multiservice irrigation-based framework we propose (Figs. 1c, 2) conceives irrigation as a means of providing a plethora of ecosystem services in compliance with the principles of input reduction, soil and animal health, recycling, biodiversity and synergy. This framework is in line with the One Health approach and targets a more sustainable food system, in which: i) the principles of land and water governance, stakeholder participation, knowledge co-creation, fairness and connectivity can contribute to achieving a more equitable distribution and use of water resources, ii) the principle of social values and diets is promoted through the integration of diversified and locally grown irrigated produce, and iii) innovations—especially technological—could help balance water and energy uses within the water-energy-food system nexus. Finally, by providing multiple services including crop production, irrigation could directly contribute to economic diversification at the farm level and within local foodsheds.

Research themes that should be addressed to provide multiservice irrigation for agroecology

Theme 1: designing field-scale multiservice irrigation

At the field scale, agroecological approaches modify soil–water–plant interactions in ways that are distinct from those of conventional systems. For instance, practices such as no-till farming, cover cropping, or polycultures can alter the soil structure, water infiltration rate and nutrient dynamics. Consequently, irrigation practices—including the scheduling, dosing and technique—must be rethought to align with and even amplify these altered processes. The ways agroecological practices interact with irrigation equipment (e.g. drip vs. sprinkler systems) should also be accounted for and optimized to provide ecosystem services. Numerical models can be used to help design irrigation systems, but further research is needed since current crop and irrigation models often fail to capture the fine interactions between agroecological and irrigation practices.

Theme 2: building irrigated agroecological farms and transformative pathways

Although irrigated agroecological farms exist, little is known about their characteristics or how they differ from conventional systems. A comprehensive assessment of the diverse range of irrigated agroecological farms is

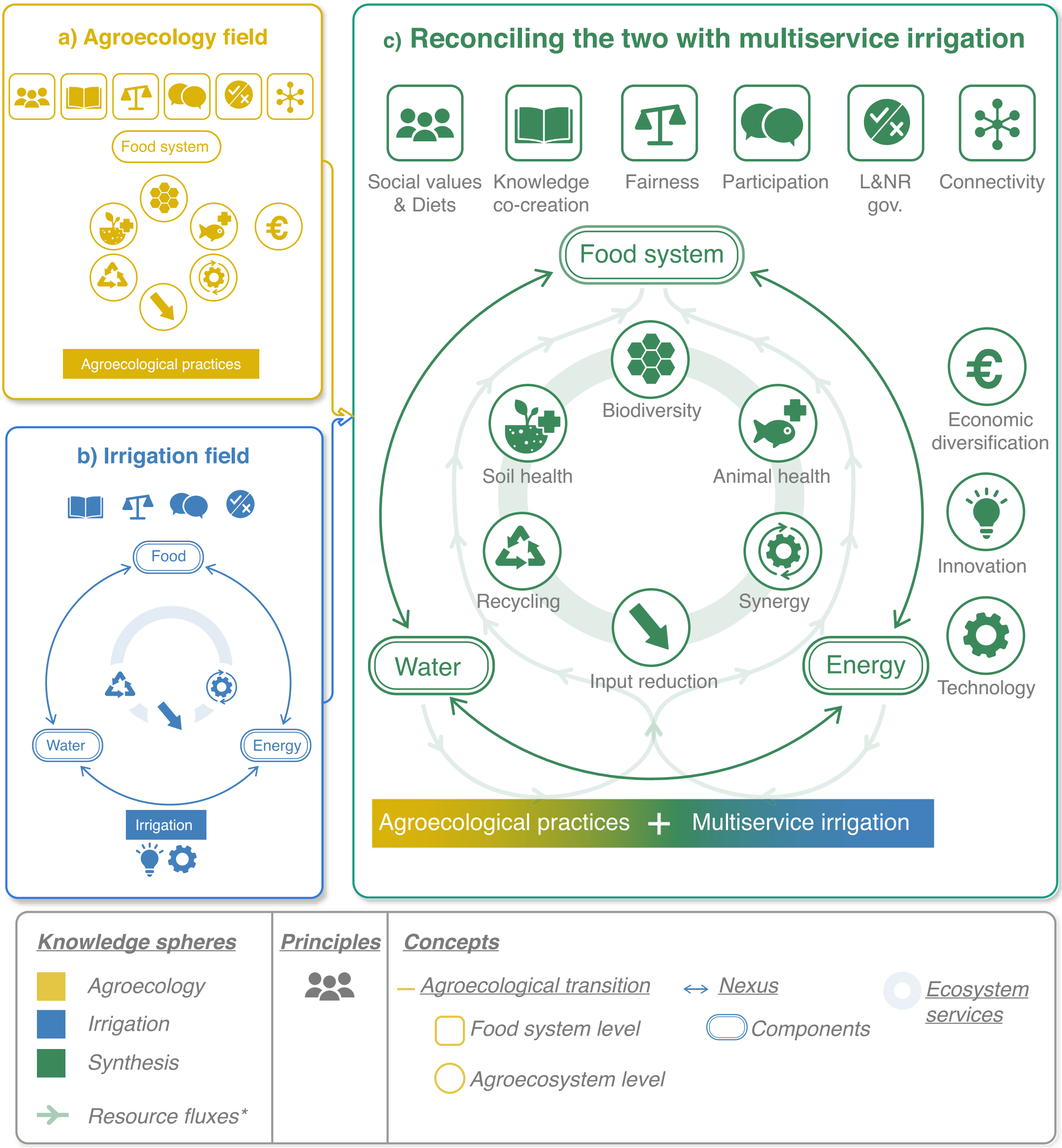

Fig. 1 | Reconciling conceptual frameworks and principles used in the fields of agroecology and irrigation. Frameworks and principles are depicted for (**a**) agroecology and (**b**) irrigation knowledge spheres, while (**c**) provides a consolidated framework that highlights the multiservice scope of irrigation. L&NR gov.: land and natural resource governance. *Indicative pathway of resource fluxes to achieve sustainable food systems.

needed at multiple scales—from individual plots to entire food systems. Research should explore not only the technical aspects (e.g. water-use efficiency and crop diversification) but also the socioeconomic dimensions, including labour dynamics, investment costs and risk management. Moreover, understanding transformative pathways within irrigated landscapes is crucial: would the transformation of current conventionally irrigated areas into agroecological systems lead to a reduction in water dependency, and could these multiservice irrigated agroecological systems exist within a wider sustainable food system (including the non-irrigated agroecological farms) without compromising water resources? Comparative studies of irrigated and non-irrigated agroecological farms could spawn valuable insight into how water management could influence broader transitions towards sustainable food systems.

Theme 3: designing hydraulic infrastructure and equipment for an agroecological transition of irrigated systems

The necessity to understand how to optimise irrigation equipment and modify its functioning, effectiveness and efficiency in cropfields has already been mentioned in Theme 1. At a broader scale, water is delivered through hydraulic infrastructure (dams, hillside storage reservoirs, canals, etc.) and its delivery is conditional to water management and governance decisions. Does the existing infrastructure constitute an opportunity or a barrier for the

Table 1 | Summary of principles that prevail in the agroecology and irrigation science fields

Agroecology principles	Irrigation science principles and corresponding references	
Recycling	**Circularity**[a]	26
Input reduction	**Efficiency**	27
Soil health		
Animal health		
Biodiversity		
Synergy	**Integrated water management**	28
Economic diversification		
Knowledge co-creation	**Knowledge and experience sharing, cross disciplinary and inter-sectoral engagement, capacity building, collective-choice arrangements**	27,29
	Innovation[b]	27
Social values and diets		
Fairness	**Equity between end-users, proportional equivalence between benefits and costs**	28,29
Connectivity		
Land and natural resource governance	**Water policy and governance, transparency, clearly defined boundaries, monitoring, graduated sanctions, nested enterprises**	27–29
Participation	**Cross disciplinary dialogue, empowerment, conflict resolution mechanisms, minimal recognition of rights to organize**	28,29
	Technology: technological knowledge, operational and technical management	27,30

Agroecological principles are derived from Wezel et al.[23]. We have listed (in bold) the principles we consider to be shared between the two fields (agroecology and irrigation science), although they are not identically designated and may refer to different spatial scales.

[a]The term circularity is not yet widely used in irrigation science, except in the recent literature on water reuse.

[b]Innovation can occur through a knowledge co-creation process, i.e. an agroecological principle, but we have not combined these two precepts here as ICID[27] refers to the technical aspects of innovation rather than the process via which it is achieved.

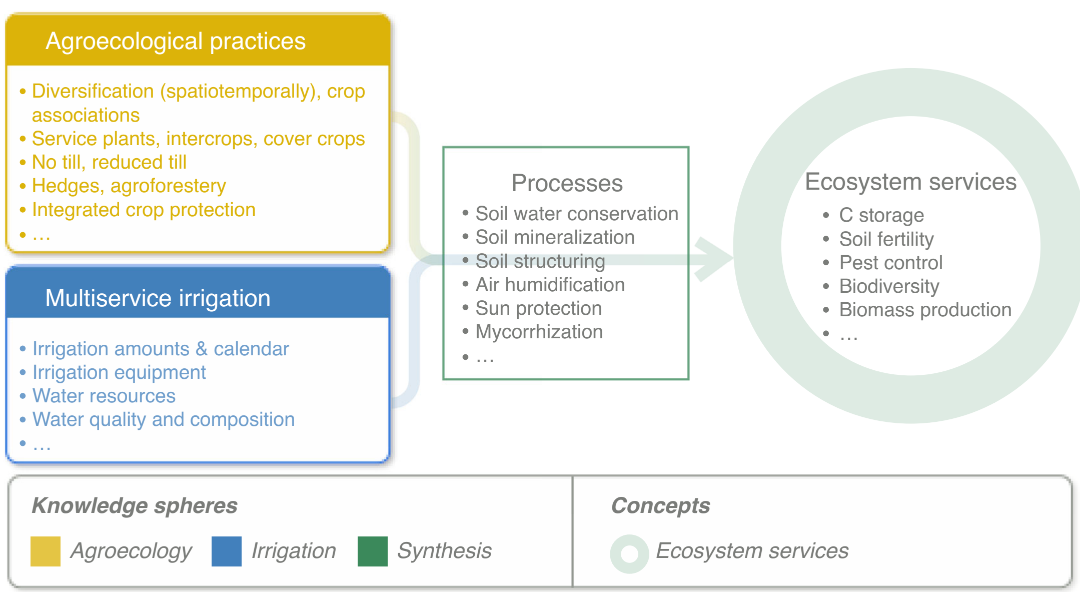

Fig. 2 | Multiservice irrigation. The interaction between agroecological and irrigation practices (left) can generate or enhance specific ecological processes and functions (middle), thereby giving rise to a range of different ecosystem services (right).

agroecological transitioning of food systems? How could this infrastructure be best mobilized to help meet agroecological objectives? Regarding water governance, the type of existing infrastructure and how it is managed could be perceived as closely related to value systems. How do hydraulic infrastructures relate (or not) to AE principles? Questions also arise as to the rules and institutions involved in infrastructure development, with macro- and micro-investments (e.g. dams vs. rainwater collectors) inherently involving more or less centralized political decision making, collective thinking and stakeholder involvement.

Theme 4: supporting the agroecological transition of irrigated systems

This research theme stresses the importance of understanding and addressing the practical challenges stakeholders face, while providing appropriate tools and environments to foster the adoption of agroecological irrigation systems. For farmers, the integration of agroecological and irrigation practices may entail changes in working hours, shifts in labor requirements, different financial risks or gender-related dynamics. For the younger generation, irrigation and AE jointly offer attractive farming opportunities. Identifying the factors and constraints that could allow/impede their combined implementation, and fostering their change, could help improve conditions for young farmers to set up in business and achieve farm viability. Other than farmers, actors such as local authorities and citizens all play critical roles in shaping the future of our food systems. It is not only important to analyse their perceptions of the role of irrigation in the agroecological transition of our food systems and the conditions for irrigation acceptability, but also to provide the appropriate analysis frameworks, participatory methods and tools (models, organizations, policies, etc.) needed for stakeholders to be involved in the agroecological transition of irrigated areas,

Theme 5: exploring the interplay between multiservice irrigation, agroecology, climate change and the water cycle

In the current urgent climate change setting, it is essential to examine the relevance of combining AE and multiservice irrigation to facilitate climate change adaptation and mitigation. Research should be focused on investigating whether irrigated agroecological systems could help mitigate climate change by providing effective carbon sinks through practices such as high biomass cover cropping systems or lower energy consumption. Life-cycle analyses and advanced modelling will be crucial to assess the climate impact of these systems under various scenarios. Concerning climate adaptation, the combination of agroecological and irrigation practices may boost the robustness of farming and cropping systems.

Finally, any comprehensive analysis of agroecological transformations must take their broader hydrological implications into account. Both irrigated and rainfed agriculture are major water resource consumers. Research must examine whether agroecological transitions in these systems could lead to increased or decreased irrigation demand, and how such changes would affect local and regional water balances. It is essential to gain insight into these dynamics in the current climate change setting, which will likely exacerbate water shortages in many regions. By analysing the impacts of agroecological practices in the framework of the larger water cycle, this aspect provides the scientific underpinning necessary for designing sustainable and resilient irrigation systems. Analysing the impact of climate change on water resources is also crucial to help design sustainable local food systems.

Theme 6: analysing and proposing public policies to foster sustainable multiservice irrigation in agroecological systems

Public policy is a powerful lever for steering agricultural practices. Current policy frameworks often compartmentalize irrigation and AE, treating them as separate issues. A critical research priority is to analyse and propose public policies that could simultaneously advance the goals of sustainable multiservice irrigation and agroecological transitions. This involves scrutinizing existing policy instruments to determine whether they inadvertently favour conventional, high-input agricultural models, and how they could be reformed to support multiservice irrigation. Policies that authorize water access conditional to the adoption of agroecological practices, for example, could lead to significant change. At the territorial level, public policies should also address the spatial distribution of irrigation systems so as to ensure that water resources are allocated in ways that reflect both the availability of these resources and local needs, while managing potential conflicts between users. This calls for a multi-scalar analysis—from farm-level interventions to regional planning—and for the development of policy instruments that reconcile the private interests of farmers and the public interests of society while remaining robust to curb the influence of entrenched agribusiness interests.

Data availability

No datasets were generated or analysed during the current study.

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C.L. and D.L. conceived the work, C.L. wrote the main manuscript text. All authors reviewed the manuscript.

Competing interests
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