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Special Issue Article

Conservation Agriculture: Towards Managing the Water-Energy-Food Nexus in India

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ABSTRACT

Depleting groundwater resources and increasing energy demand with the huge dependence of India's agriculture on groundwater and energy, and especially in water deficit rice-based production systems, are posing a serious threat to sustained food, water, and energy security. Sustainability concerns of water, energy, and input-intensive rice-based crop production systems have increased the realization for developing and scaling up alternative agro-techniques that can significantly reduce the water and energy requirements in crop production without compromising on crop yield. The interconnectedness between water, energy, and food makes the concept of water, energy, and food (WEF) nexus more relevant to explore integrated solutions to efficient use of limited and/or declining water and energy resources. Conservation agriculture (CA) is gaining currency as an alternate system for rice/cereal-based production systems to conserve water and energy, improve soil health, reduce cost of cultivation, and preserve ecology. This paper explores the concept of WEF nexus and how CA addresses the challenge of harmonizing the synergy among water, energy, and food though WEF 'nexus gains' especially in the context of groundwater irrigated rice/cereal based cropping systems.

Key words: Water-energy-food nexus, conservation agriculture, groundwater, rice

Background

Water is essential for human health and well-being, and central to the achievement of food security and sustainable development goals (SDGs). Water and energy are the key determinants of agricultural production and food security (Ambast, 2017). Agricultural energy consumption includes both direct and indirect energy consumption. Direct use of energy in agriculture production is required from tillage and field operations in sowing to harvesting and to lifting water from groundwater and surface water sources for irrigation. Indirect energy consumption includes the use of fuel and feedstock (especially natural gas) in the manufacturing of agricultural inputs such as fertilizers and pesticides (USEIA, 2013). Adequate access to and management of water and energy resource is therefore key to sustainable agriculture development. With limited land resources for agriculture, growing water stress, and inadequate energy supply most of the South Asian agriculture faces the challenge of water and energy to grow food for the burgeoning population and changing lifestyles, dietary and food habits (Rasul, 2014).

Given the huge dependence of India's agriculture on groundwater and energy, and depleting groundwater resources especially in water deficit rice-based production systems, are posing a serious threat to sustained food security. This is further exacerbated because of climate

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change as groundwater is likely to be affected by climate change. Sustainability concerns of water, energy and input-intensive crop production systems have increased the realization for developing and scaling up alternative agro-techniques that can significantly reduce the water and energy requirements in crop production and along the value chain (Kumar *et al*., 2020; Saad *et al*., 2016; Bahtt *et al*., 2016). Increasing demand for food, water and energy led to the discourse on the inter-connectedness of water, energy, and food (Shah *et al*., 2004; Kumar and Gurung, 2015). Therefore, co-management of water and energy for sustainable food systems in a nexus approach is critically important as water, energy, and food systems derive sustenance from shared natural resources.

Groundwater and Energy Intensive Agriculture

Annual per capita water availability in India is down from 5300 m^3 in 1951 to about 1400 m^3 at present, barely sufficient to sustain economic growth and support human well-being. It is projected to be 1340 and 1140 m^3 by 2025 and 2050, respectively. Indian agriculture consumes about 82% of total freshwater withdrawals and increasing area under irrigation is creating pressure on both surface and ground water resources. Diversion of fresh water for agriculture in India is likely to reduce due to competing water demands in the future and some estimates have put it as 72% by 2025, and 65-68% in 2050 (ADB, 2013).

Over the last four decades, around 84 per cent of total addition to the net irrigated area has come from groundwater with India drawing about 250 billion cubic metres (BCM) every year which is more than any other country in the world (CGWB, 2019). With groundwater becoming major source of irrigation supporting 63% of irrigated area and with 90% of groundwater withdrawal being used for irrigation, over-exploitation of aquifers is becoming a serious risk (CGWB, 2019). The number of groundwater irrigation structures went from 6.2 million in 1986–1987 to 20.5 million in 2013–2014 (Mukherji, 2020). Out of the total 6,881 assessment units (blocks/mandals/talukas/ firkas), 17% of the units in various States (17%) have been categorized as '*Over-Exploited*' indicating groundwater extraction exceeding the annually replenishable groundwater recharge. While 5% of the assessed units are '*Critical*' with groundwater abstraction ranging between 90-100% of recharge (CGWB, 2019). The increasing groundwater use, and declining groundwater levels also entail higher energy requirement.

Agricultural operations like tillage, sowing/ transplanting, pumping water for irrigation, harvesting, and threshing use a significant amount of energy for crop production. Energy consumption in agriculture surged post Green Revolution with Indian agriculture using about 20-22 percent of total energy consumed in India (NPC, 2009). A major portion of the electricity consumed in agriculture sector is used for groundwater pumping. According to Central Electricity Authority (CEA), around 90% of electricity supplied to agriculture is used for groundwater pumping, and this has increased by 54 times between 1970-2016 (Dharmadhikari *et al*., 2018). About 72 percent of the total ground water irrigation is powered by grid electricity and 23.70 percent by diesel (Rajan *et al*., 2020). Using the Minor Irrigation census data (2014-15), Rajan *et al*. (2020), estimated that groundwater irrigation consumed 198-272 billion kWh of energy, releasing 45.3-62.3 MMT of carbon in one year. This clearly indicates that Indian agriculture is not only water intensive but also energy and carbon intensive. As a result, the irrigation economy of the region has become overwhelmingly dependant on pumping of groundwater and India has become – by far – the world's largest user of groundwater.

Rice-based cropping system is the major cropping system practised in India. In the irrigated and favourable rainfed lowland areas, rice-rice (R-R), rice- wheat (R-W), and rice-maize (R-M) are the predominant cropping systems. About 55% of the rice area in India is irrigated. Rice-wheat is the dominant cereal-based system in South Asia, with Indo-Gangetic Plains (IGP) of India alone occupying 10.5 million ha area under rice-wheat cropping system (Das *et al*., 2018). Rice-based cropping systems are the most water and energy intensive production systems in India and most of South Asia (Hazra *et al*., 2019, Nandan *et al*., 2021). Sharma *et al*. (2018) identified three "water guzzler" crops – rice, wheat, and sugarcane – which occupy about 41 percent of the gross cropped area and consume more than 80 per cent of irrigation water. Sustainability of the rice-based cropping systems, particularly in north-west India, is under question with fast depleting groundwater resources, growing energy demand, deteriorating soil health, environmental pollution, and declining factor productivity. Declining groundwater table is further adding to energy consumption, and as per one estimate one percentage fall in water table will increase energy consumption by 1.25-1.5%. In areas with free or highly subsidized electricity for pumping groundwater like Punjab and Haryana, the threat is looming large. Results of a recent study (Jain *et al*., 2021) using high-resolution satellite and census data from India suggest that, given the current depletion trends, cropping intensity may decrease by 20% nationwide and by 68% in groundwater-depleted regions in India.

Growing water shortages are compelling us to focus more on re-designing intensive cereal systems through developing resource efficient and remunerative practices for increasing water and energy productivity and farmer's profitability in irrigated cereal systems, especially in NW India (Singh *et al*., 2014, Jat *et al*., 2019a). Producing more with less water and energy will therefore be a challenging task. To address this double whammy, relevance of alternate practices like Conservation Agriculture (CA) system for conservation of water and energy resources is being realized for sustainable production.

The inextricable linkages between water, energy, and food therefore makes the concept of water, energy, and food (WEF) nexus more relevant to explore integrated solutions to efficient use of limited and/or declining water and energy resources for sustainable production system (Rasul, 2014). Conservation agriculture (CA) is gaining importance as an alternate system for cereal based production system to conserve water and energy, improve soil health, reduce cost of cultivation, and preserve ecology. This paper presents the concept of WEF nexus and its relevance in the context of groundwater irrigated rice/cereal based cropping systems with a focus on CA in conserving water and energy while sustaining agricultural productivity.

Water-Energy-Food Nexus in the Context of Groundwater Irrigated Agriculture

International Water Management Institute (IWMI), India has been among the first to recognize and highlight the importance of WEF nexus around 2003-04 much before the Bonn 211 Nexus Conference (Shah *et al*., 2004; Verma and Phansalkar, 2007; Shah and Verma, 2008; Verma *et al*., 2009; Mukherji *et al*., 2010; Verma, 2010; Shah *et al*., 2018). IWMI's work has for long argued that energy and food policies can have significant impact on water management and governance. The issues and challenges in food, water, and energy sectors are interconnected in complex ways and their effective management is not possible without cross-sectoral integration (Rasul, 2014).The WEF nexus approach recognizes the interdependencies of water, energy, and food production which aims to systemize the interconnections and provide a framework for assessing the use of all resources and to manage trade-offs and synergies (Shah *et al*., 2004; Bazilian *et al*., 2011; Scott *et al*., 2011; Hermann *et al*., 2012; Hussey and Pittock, 2012; Sharma and Bazaz, 2012). Recognizing that efficient use of these limited and/or degrading and declining resources is essential to sustainability, the World Economic Forum (2011) first initiated dialogue on 'Nexus thinking' to promote the inseparable links between the use of resources to provide basic and universal rights to food, water, and energy security (Biggs *et al*., 2015). The Bonn 2011 Nexus Conference, the sixth World Water Forum, and World Water Week 2012, were amongst the few more to have urged for an integrated approach to food, water, and energy security. The Bonn Nexus Conference presented a framework to address unsustainable pattern of growth and impending resource constraints framed around water availability and interdependencies needed to achieve water supply, energy, and food security.

The WEF nexus approach, as a systems-based perspective, aims to maximize synergies (mutually beneficial outcomes) and minimize trade-offs (which may potentially include non-optimal outcomes), improve resource-use efficiency, and internalize social and environmental impacts, particularly across a range of contexts and scales (Kurian, 2017). The interdependence among water, energy and food is such that action and policy in one sector will usually have impacts on the other sector(s). Understanding these linkages therefore helps in taking suitable actions or interventions and provides opportunities for negotiating policy coherence among these three key sectors (Rasul and Sharma, 2016; Mukherji, 2020). This helps to strengthen cross-sectoral integration, improve management outcomes to enhance water, energy, and food security and helps promote interdisciplinary and mutually beneficial actions (Scott *et al*., 2016).

The WEF nexus is also being promoted as a conceptual framework for achieving sustainable development and it has become central to discussions regarding the development and subsequent monitoring of the SDGs. WEF nexus, for instance has a potential role to play in the realization of the SDG-1, SDG-2, SDG-6, SDG-7 and SDG-13 besides aligning with the objectives of achieving Nationally Determined Commitments (NDCs) envisaged in the 2015 Paris Agreement on Climate Change.

Figure 1 is a simple illustration of WEF nexus in irrigated agriculture. Water as a unifying thread or connector across this intrinsic relationship among water, energy and food with a vital role in food and energy production. Energy is required for food production (mostly in land preparation, tillage, and irrigation) and for lifting water for water supply and distribution besides indirect use in producing fertilizer. Agriculture, responsible for growing food, is a major consumer of water and energy. Agricultural practices also impact land degradation, runoff and local hydrology,

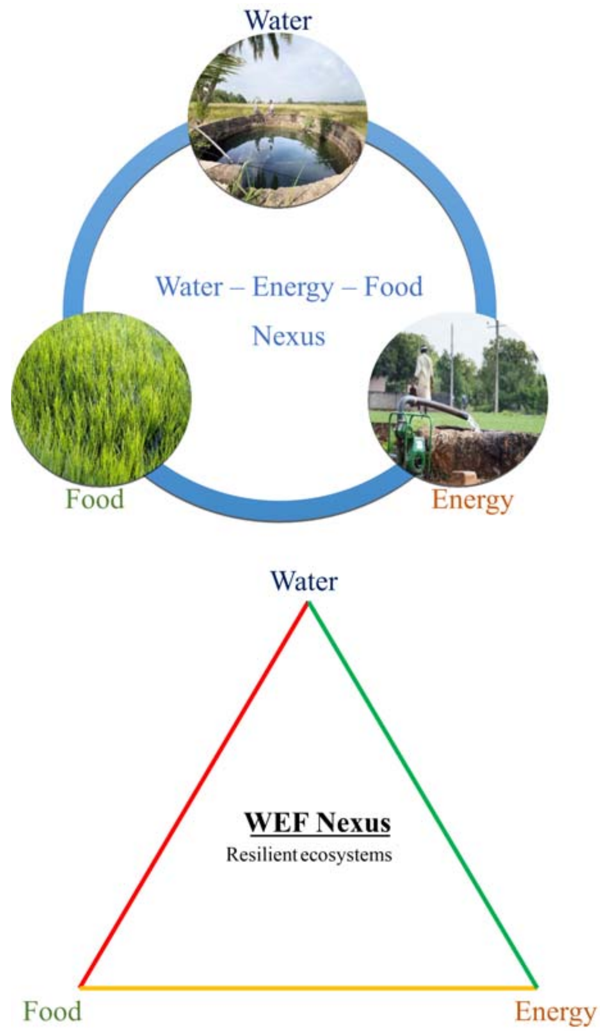

Fig. 1. Illustration of WEF nexus to irrigated agriculture

infiltration, soil moisture and groundwater recharge which have implications on water availability and quality. An example of 'nexus gains'- integrating agricultural water productivity gains through efficient water management for reduced energy and water consumption, with energy efficient measures (e.g., efficient pumps) would reduce water and energy footprints. On the other hand, an example of 'nexus losers'- free and/or highly subsidized electricity for pumping groundwater for irrigation and inefficient water management leads to more water intensive energy mix options.

In India, unsustainable use of groundwater and energy supported by policies of free and/or highly subsidized energy and attractive minimum support price (MSP) for key crops including rice and wheat is an excellent example of WEF nexus, especially in groundwater irrigated rice-based food production system in north-west India (Mukherji, 2020).Climate change is further exacerbating these problems. The nexus approach provides a framework for addressing competition for shared resources and enhancing resource use efficiency with a cross-sectoral focus. The subsequent section explores how conservation agriculture (CA), which is gaining currency as one of the integrated approaches to manage water, land, and energy for sustainable crop production, is important from WEF nexus lens.

Conservation Agriculture in the Context of WEF Nexus

Conventional practice of growing rice with land preparation, tillage, puddling, frequent irrigation with standing water during crop growing period and excessive and/or imbalanced fertilizer application make it more water and energy intensive. Conventional cultivation practices of rice-wheat (RW) system consume 2150–2300mm irrigation water for crop production (Choudhary *et al*., 2018). Conservation agriculture (CA) is emerging as an alternative to conventional tillage-based agriculture. CA is a management system that maintains a soil cover through surface retention of crop residues with no till/zero till and reduced tillage. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production (FAO, 2020) (http://www.fao.org/conservation-agriculture/en/). According to CIMMYT, conservation agriculture is based on the interrelated principles of minimal mechanical soil disturbance, permanent soil cover with living or dead plant material, and crop diversification through rotation or intercropping (https://www.cimmyt.org/news/what-is-conservation-agriculture/). In summary, key elements of CA include practices and approaches of no-tillage, adequate retention of crop residues on the soil surface for mulching, innovative cropping systems and measure to reduce soil compaction (Jat *et al*., 2019a, b; Jat *et al*., 2020).

Conservation agricultural systems are gaining attention to reduce the water footprint of growing crops by improving soil water infiltration, increasing soil moisture retention, and reducing runoff and contamination of surface and ground water. This also reduces energy use in agriculture due to reduced/no-tillage and reduced water footprint also leads to reduced energy consumption in pumping groundwater for irrigation. The CA technologies thus provide opportunities to save water and nutrients, reduce energy use, increase yields, reduce cost of production, increase crop diversification, improve efficient use of inputs, and benefit the environment, which is a good example of ‘Nexus Gains’.The ‘nexus gains’ here refers to yield gains with making integrated use of resources through CA via gains in enhanced water and energy use efficiency/productivity with reduced water and energy footprints.

Documented field-based evidence of CA in conserving water and energy, improving soil health and increasing system level crop productivity demonstrates the interconnectedness between water, energy, and food sectors at the cropping system level. Field evidence on conservation agriculture has shown that targeted CA-based management practices portfolio has potential to produce more food (10-15%) from less water (20-75%) and less energy (20-45%) while lowering carbon footprints by 25-30% (Jat *et al*., 2019a). A meta-analysis of CA based practices in South Asia shows a mean yield advantage of 5.8% with 12.6% higher water use efficiency and a reduction of 12–33% in global warming Potential (GWP) which could be attributed to efficient use of water, energy, and fertilizer (Jat *et al*., 2020). Studies conducted by Kakraliya *et al*. (2018) in a rice-wheat (RW) rotation of western Indo Gangetic plains revealed that bundling of various management practices with CA in Rice-Wheat rotation improved system productivity by 6 % and saved 22% of irrigation water and improved water productivity (WP)

Table 1. Performance of CA based management practices, diversification, and bundled solution in intensive cereal systems

Management scenarios	System grain yield (t ha^{-1} yr^{-1})	Irrigation (mm ha^{-1})	WP_I (kg grain m^{-3})	Energy use efficiency (MJ ha^{-1})
Business as usual- conventional tillage-based flood irrigated rice-wheat (RW) system	13.37	2321	0.58	4.90
Intensification of RW system: Rice-wheat-mungbean with CA and flood irrigation	14.03	2004	0.70	5.76
Diversification of RW system: Maize -wheat (MW)-mungbean with CA and flood irrigation	15.33	651	2.37	10.30
Sustainable Intensification of RW system: Rice-wheat-mungbean with CA and sub-surface fertigation	14.87	1068	1.42	7.90
Sustainable Intensification of MW system: Maize -wheat-mungbean with CA and sub-surface fertigation	16.00	360	4.46	12.16

Adapted from Jat *et al*. (2019)

(Irrigation) and WP (irrigation + rain) by 37 and 26% on a 3 year mean basis, respectively over the farmers' practice. In a recent study, Jat *et al*. (2019b) compared bundling of conservation agriculture (CA) with sub-surface drip irrigation (referred as CA+) with CA alone and conventional tillage-based flood irrigated RW rotation. In comparison to conventional till RW rotation, CA+ system saved 58.4-95.5% irrigation water, recorded 11.2% higher crop productivity, improved irrigation water productivity by 145%, and improved energy productivity by 75 -169% over the conventional farmers' practice (Table 1).

Likewise, Nandan *et al*. (2021) have assessed different CA modules in rice-based cropping systems for energy conservation through field experiments at Patna in the eastern IGP. They evaluated four different tillage-based crop establishment modules i.e. puddled-transplanted rice followed by conventional-till maize/wheat (CTTPR-CT), non-puddled transplanted rice followed by zero-till maize/wheat (NPTPR-ZT), zero-till transplanted rice followed by zero-till maize/wheat (ZTTPR-ZT), and zero-till direct-seeded rice followed by zero-till maize/wheat (ZTDSR-ZT)), with two residue management treatments (residue removal, residue retention) in rice–wheat and rice–maize rotations following energy budgeting. These conservation-tillage treatments reduced the energy requirements over conventional tillage treatments, with the ZTTPR-ZT and ZTDSRZT treatments showing greater reduction. Energy savings were attributed to reduced energy use in land preparation (69–100%) and pumping water for irrigation (23–27%). Conservation-tillage treatments also increased grain and straw/stover yields of crops leading to increased energy productivity (23–34%) over the CTTPR-CT. Conservation tillage treatments reduced energy use in land preparation (1264–3272 MJ ha$^{"1}$), irrigation (8314–9843 MJ ha$^{"1}$).The results of another study also showed that no till drilling saved time, energy and cost by 70.1, 67.2 and 67.3%, respectively as compared to the conventional tillage in wheat (Jat *et al*., 2020).

There is therefore ample field evidence to suggest that conservation agriculture in cereal-based production system could be a sustainable alternative to conventional tillage-based agriculture in conserving water and energy and increased crop productivity. Bundling CA with the portfolio of practices from proven component technologies such as laser levelling, smart irrigation scheduling, sub-surface drip/fertigation add more value in contributing to the three elements of the WEF nexus triangle. Figure 2 illustrates how CA, as a systems approach, can help harmonize synergies among the three interconnected elements in a WEF nexus.

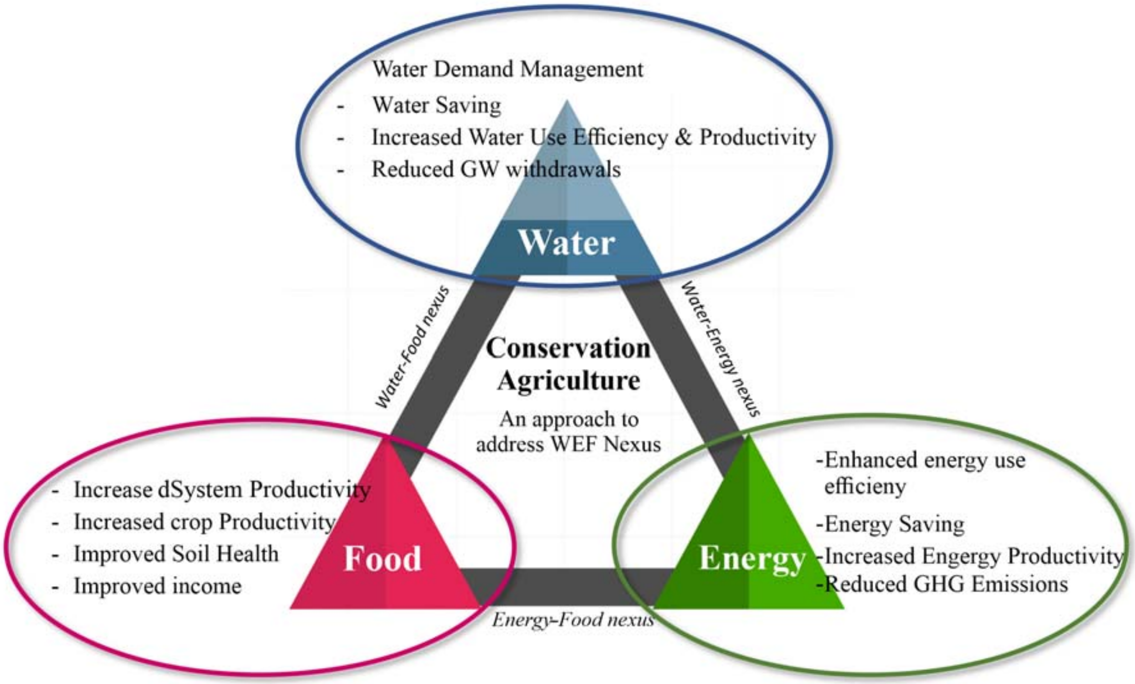

Fig. 2. Conservation agriculture in addressing WEF nexus

Way Forward

The concept of CA got attention during mid-nineties with the launching of Rice-Wheat Consortium (RWC) for the Indo-Gangetic Plains. Development and promotion of CA has been made through the combined efforts of ICAR institutes, several State Agricultural Universities, and CG Centres. The spread of CA technologies has largely been in the irrigated regions of the Indo-Gangetic plains dominated by rice-wheat/ cereal based cropping systems. Development programmes of the government like National Mission for Sustainable Agriculture (NMSA) and others have provision for promoting CA technologies. The promotion of CA technologies has been underway for almost two decades and it is only during the last one decade that the adoption of CA technologies has received acceleration though the pace is still slow. This raises opportunity to study area/context specific technological, institutional and policy related barriers besides social and behavioural aspects to adaptation of CA by farmers at large scale to harness its fullest benefit.

Looking at the growth of groundwater irrigated area and given that it is more climate resilient because of its higher buffering capacity and likely less impacted by climate change than surface water, groundwater will remain a preferred source of irrigation (Sikka *et al*., 2020). It is also obvious that crop choices are influenced by policies related to electricity/energy and availability of MSP than the water. Considering these scenarios, adoption of CA technologies at large scale with a targeted focus on groundwater irrigated rice-based production systems would need a greater policy push. Bringing policy coherence across water, food and energy policies for 'nexus gains' is need of the time.

Promoting adoption of CA in large scale should stress on developing scalable business models involving rural youth and women, local entrepreneurs, creating effective custom hiring centres for scale appropriate machinery, CA mechanization hubs, building partnerships, enhanced capacity development of all stakeholders including farmers and service providers. This would also require a policy which is focused exclusively at enabling promotion of

CA technologies to provide integrated solution for sustainable use of shared natural resources within the WEF nexus.

Conclusion

India is the world's largest consumer of groundwater, and no other agricultural production system in the world depends as much on groundwater as India does. The increasing water and energy demand for sustaining agriculture production and food security in the face of competing demand from other sectors with fast-depleting groundwater resources, especially in the north western India and rice- based farming systems deserve serious attention to more efficient and alternative solution to intensive tillage-based cultivation. Field based science evidence from field experiments and scale pilots suggest the relevance of CA technologies for conservation of water and energy while increasing productivity as a win-win alternate proposition. This proposition harnesses interconnectedness of water, energy, and food for harmonized nexus thinking. Integrating CA with other context specific best component practices will avoid secondary consequences of action due to one action/policy and help bring policy coherence. Innovative business models for promoting CA at development scale, more policy push, effective custom hiring centres and capacity development deserve much needed impetus for addressing WEF nexus with wider adoption of CA.

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