

**International Journal of Innovative Research in Science,
Engineering and Technology**

(An UGC Approved, High Impact Factor, Monthly, Peer Reviewed Journal)

UGC Approval No: 48027

Vol. 6, Issue 12, December 2017

Alternative Cropping System and Optimised Management Practices for Saving Groundwater and Enhancing Environmental Sustainability

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ABSTRACT: Alternative cropping systems such as conservation agriculture and organic farming are expected to decrease negative impacts of conventional systems through sequestration of organic carbon in soil and mitigation of greenhouse gas emissions. An alternative field crop could be defined as an agronomic crop not usually grown in a geographic region, selected for use due to potential high sale value or specialized benefit to the farming system. Alternative crop options can also include modifying production practices resulting in a higher value product. Examples include certified seed production and certified organic production. These seemingly unconnected ideas have similarities, both requiring third-party certification. These practices require increased management attention by the grower and often involve increased production costs, but offer price premiums and additional markets. Rapid decline in groundwater table due to excessive withdrawal of water for irrigation has been posing a serious threat to sustainable agricultural production in hot arid region of India. Alternative cropping systems having low irrigation requirement have been proposed to resolve unsustainable groundwater use.

KEYWORDS: alternative cropping, systems, conservation, irrigation, organic, unsustainable, groundwater, farming

I. INTRODUCTION

In a study, an integrated analysis of amount of groundwater use, productivity, profitability, resource-use efficiency (RUE), and environmental impacts of three cluster bean-based cropping systems [conventional cluster bean (*Cyamopsis tetragonoloba*)–wheat (*Triticum aestivum*) (CB–W), and two alternative cropping systems, namely cluster bean–Indian mustard (*Brassica juncea*) (CB–IM) and cluster bean–blond psyllium (*Plantago ovata*) (CB–BP)] under different soil management practices [two tillage types, i.e., conventional (CT), and deep tillage (DT); and three farmyard manure[1,2] (FYM) application rates, i.e., 0, 5, 10 Mg ha⁻¹] was carried out. Based on a three-year field experiment, compared to conventional CB–W, alternative cropping systems produced 28.6–47.4 % lower seed yield, but enhanced economic returns (7.6–31.1 %), while reduced amount of irrigation (– 27.9 to – 37.2 %), energy (– 22.4 to – 37.0 %), and nutrient (– 17.4 to – 46.1 %) used, global warming potential (– 20.2 to – 45.9 %) and greenhouse gas intensity (– 27.3 to – 57.7 %). Alternative cropping systems saved 1.87–2.50 × 10³ m³ per year per hectare of groundwater than conventional cropping systems. Soil management practices influenced agro-economic and environmental dimensions of cropping systems. Deep tillage (DT) enhanced yield (14.0 %), economic profit (18.8 %), RUE (13.2 %, 13.8 % and 8.5 % for nutrient, water and energy use efficiency, respectively).[3,4] Addition of FYM increased yield (up to 23.0 %), economic net return (up to 21.8 %), RUE (up to 22.7 %, 16.5 %, 91.0 % in water, energy and nutrient use efficiency), and reduced global warming potential (up to – 7.9 %). The CB–BP cropping system with DT and FYM addition offered the best balance of yield, profit, saving of irrigation water, energy and nutrient, while minimizing GWP. This study provides empirical evidence of the opportunities for alternative cropping systems which balance the multiple objectives of sustainable groundwater use, farmer profitability and

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environmental sustainability for arid region of India. The results have direct implications for sustainable utilization of underground water for similar regions of the world facing water shortage.[5,6] Punjab and Haryana are switching to sustainable cropping techniques to preserve groundwater. Groundwater levels in both states have been on a rapid decline. According to the Central Ground Water Board (CGWB), it decreased by about 85 percent in Punjab between 1984 and 2016. Haryana's groundwater depletion rate is among the highest in the country. In Punjab and Haryana, the sown area shifted to other less water-intensive crops in recent years. Parts of the states have moved to alternative sowing methods and away from water-intensive crops this Kharif season. Punjab brought 600,000 hectares under direct-seeded rice (DSR), an alternative for the traditional, water-intensive method of sowing rice. Haryana has also been promoting DSR and the state government announced to give Rs 5,000 per acre to farmers opting for this technology. [7,8]

Significance of DSR: It can help reduce water consumption by as much as 35 percent over the traditional process of transplanting rice seedlings from a nursery to waterlogged fields. It is also the second year for Haryana's 'Mera Pani Meri Virasat' scheme, under which an incentive of Rs 7,000 is being given to farmers to switch from paddy. For this scheme, the government is specifically targeting eight paddy-rich blocks where the groundwater levels have dropped below 40 metres.[9,10]

II. DISCUSSION

Causes of Groundwater Depletion

Frequent Pumping: Groundwater depletion most commonly occurs because of the frequent pumping of water from the ground. It leads to a dangerous shortage in the groundwater supply.

Aquifers are insufficient: While aquifers hold enough water, it doesn't have the ability to recollect quickly enough to be continually sourced for our use.

Requirements in Agriculture: Agricultural needs require a large amount of groundwater, but the availability of groundwater is steadily declining. It is becoming extremely difficult to provide drinking water and water for crops and animals.[11,12]

Natural depletion: Groundwater depletion can also occur naturally. The activities that lead to groundwater depletion come mostly from humans, but a portion of it also comes from climate change.

Impact of Groundwater Depletion

Lesser water available at deeper levels: Groundwater depletion will force us to pump water from deeper within the Earth. Consequently, there will be a need to use even more resources to develop alternative methods to reach further into the ground.

Affecting Freshwater Supply: The groundwater is responsible for providing up to 40% of freshwater in the world. The depletion will affect the Earth's freshwater supply.

Water content in large bodies will start to reduce: Large bodies of water will become more shallow from groundwater depletion. This means that over time, less water will enter as the existing surface water continues to evaporate.

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Saltwater Contamination & Price Rise: When freshwater mixes with saltwater, it is called saltwater contamination. This could raise the prices of drinking water for everyone because it will cost much more to pump and filter. [13]

Food supply will suffer: As large aquifers are depleted, food supply and people will suffer.

Biodiversity will be affected: A lack of groundwater limits biodiversity and dangerous sinkholes result from depleted aquifers.

As the water becomes less deep, it will affect everything in that particular region, including fish and wildlife.

Drip Irrigation-Drip irrigation systems deliver water directly to a plant's roots, reducing the evaporation that happens with spray watering systems. Properly installed drip irrigation can save up to 80 percent more water than conventional irrigation, and can even contribute to increased crop yields.

Capturing and Storing Water-Many farms rely on municipal water or wells (groundwater), while some have built their own ponds to capture and store rainfall for use throughout the year. Properly managed ponds can also create habitat for local wildlife. Marin Roots Farm relies on two ponds for all of their water needs, helping to minimize their impact on the surrounding watershed. [14,15]

Irrigation Scheduling -To avoid under- or overwatering their crops, farmers carefully monitor the weather forecast, as well as soil and plant moisture, and adapt their irrigation schedule to the current conditions. Timers can be used to schedule watering for the cooler parts of the day, further reducing water loss.

Drought-Tolerant Crops-Growing crops that are appropriate to the region's climate is another way that farmers are getting more crop per drop. Crop species that are native to arid regions are naturally drought-tolerant, while other crop varieties have been selected over time for their low water needs.

Dry Farming-Relying on soil moisture to produce their crops during the dry season. Special tilling practices and careful attention to microclimates are essential. Wine grapes, olives, potatoes, and apple trees can also be successfully dry farmed in California.

Rotational Grazing-Rotational grazing is a process in which livestock are moved between fields to help promote pasture regrowth. Good grazing management increases the fields' water absorption and decreases water runoff, making pastures more drought-resistant. Increased soil organic matter and better forage cover are also water-saving benefits of rotational grazing.

Compost and Mulch-Compost, or decomposed organic matter used as fertilizer, has been found to improve soil structure, increasing its water-holding capacity. Farmers may also use black plastic mulch as a soil cover to suppress weeds and reduce evaporation.

Cover Crops-Planted to protect soil that would otherwise go bare, cover crops, reduce weeds, increase soil fertility and organic matter, and help prevent erosion and compaction. This allows water to more easily penetrate the soil and improves its water-holding capacity.

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Conservation Tillage-Conservation tillage uses specialized plows or other implements that partially till the soil but leave at least 30 percent of vegetative crop residue on the surface. Like the use of cover crops, such practices help increase water absorption and reduce evaporation, erosion, and compaction. [16,17]

Going Organic-In addition to keeping many of the more toxic pesticides out of our waterways, organic methods could help retain soil moisture. Healthy soil that is rich in organic matter and microbial life serves as a sponge that delivers moisture to plants.

Use less water for luxury purposes: Considering the impending crisis of a mass water shortage, everyone should do their part to use less water whenever possible.

Reduce chemical use: The water from businesses and private residences that run into the streets and sewage systems are commonly laden with chemicals. Reduce use of chemicals and dispose of them properly.

Investment in R&D: More comprehensive research and additional funding can help with groundwater depletion. Understandably, more funding should be granted towards researching our groundwater supply instead of just pumping the water.

Strict Laws-Laws that are in place for the pumping of groundwater should be more strict and follow specific regulations.

Find alternative sources of water: One of the most effective ways to address the issue of groundwater depletion is to find alternative sources of water. Alternative water sources can be used to help replenish aquifers. Deriving water from other sources would also give aquifers time to refill instead of pumping too much water from them at once. [18,19]

Regulated pumping: The pumping of groundwater should be regulated. If we don't have a better understanding of our groundwater supply, then we can easily use much more than we should.

III. RESULTS

We overcome previous challenges to empirically estimate the impacts of groundwater loss on agricultural production by using a novel satellite data product that we developed that measures winter cropped area, the key determinant of cropping intensity, at fine spatial resolution ($1 \times 1 \text{ km}^2$) across India. We link these data with high-resolution village-level census data on the amount of shallow well, deep well, and surface water irrigation in each village. We focus on winter cropped area because almost all farmers plant crops during the monsoon season, few farmers plant crops during the dry summer season, and winter agriculture is primarily dependent on groundwater for irrigation. We also assess the effectiveness of a potential supply-side government policy, namely, expanding canal irrigation to regions that are facing severe groundwater depletion. We focus on this potential adaptation strategy because canal expansion is being widely promoted by the Indian government as a way to deliver irrigation water to regions with dwindling groundwater resources. By using high-resolution data on irrigation and agricultural production, we are able to directly link measures of crop production with specific types of irrigation infrastructure, providing information about their relative efficacies. In addition, because the efficacy of groundwater and canal irrigation likely varies across the country depending on local investments in infrastructure and on a region's climate and geology, these high-resolution data allow us to quantify this heterogeneity. [20,21]

Across India, we find that tube well irrigation use is associated with a higher likelihood that farmers plant crops in the winter growing season, a higher proportion of cropped area in villages growing a winter crop a lower coefficient of

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variation in cropped area and less sensitivity of cropped area to monsoon rainfall variability when compared with the use of canal and dug well irrigation sources . Specifically, our regression results show that farmers in canal-irrigated villages are 52% less likely to plant a winter crop than farmers in tube well-irrigated villages . Furthermore, farmers in canal-irrigated villages who do plant a winter crop have only 78% (or 22% less) of the winter cropped area found in similar tube well-irrigated villages . By comparison, we find no significant differences between the association of winter cropped area and dug well versus canal use . These results and all subsequent results are robust to the inclusion of a suite of biophysical and socioeconomic factors as controls to cross-sectional regressions, state as a fixed effect in all cross-sectional regressions, village as a fixed effect in panel regressions, and clustered SEs at the district scale in all regressions to account for spatial autocorrelation across villages.

We find that canal irrigation may serve as a viable substitute for groundwater irrigation in certain parts of the country despite having limited capacity as an adaptation strategy at the national scale. Specifically, canal irrigation is associated with equal crop production as groundwater irrigation in the western Indo-Gangetic plains and with increased crop production in South India. This variation in canal efficacy is likely due to differences in aquifer geology, irrigation policies and subsidies, and historical investment in irrigation technologies. For example, in the western Indo-Gangetic plains, there has been a long history of investment in canals, resulting in higher irrigation output compared with canals in other parts of India .[22,23] In South India, wells are not as high yielding as in other parts of the country because they are drilled into shallow hard rock aquifers that deplete and replete annually, making wells perform similarly to canals . While canals have the potential to adequately serve as a substitute irrigation source in South India, this region will likely not be able to compensate for potential losses to production projected in Central and North India . This is because South India produces a small fraction of the nation's winter crop , and the entirety of India's wheat is planted in Central and North India during the winter growing season , suggesting that there may be large reductions in national wheat production if farmers switch away from groundwater to canal irrigation in the future. This is of concern given that India is the second largest producer of wheat globally , and wheat provides approximately 20% of household calories across the country .[24,25]

IV. CONCLUSIONS

First, we assume 100% loss of access to critically depleted groundwater; however, it is likely that some farmers will maintain some access as water tables decline, either by paying higher costs or using annually refilled shallow aquifers. Work however, supports the assumption that farmers will lose access to irrigation as groundwater tables fall as they found that groundwater depletion is associated with reductions in winter cropped area across India. Second, we assume that canal irrigation will be able to reach all farmers that currently have access to well irrigation, yet there are likely physical and infrastructural constraints to expanding canal irrigation at such a scale. Third, we did not incorporate potential recharge to groundwater that may occur if canals are expanded, although previous work has shown that canal expansion will do little to reduce stress on overexploited aquifers . Fourth, our winter cropped area data do not distinguish between crop types, and it is possible that farmers are adapting to groundwater depletion by switching to less water-intensive crops; if this occurs,[26] we likely would see smaller shifts in cropped area as groundwater tables fall because farmers are instead adjusting their crop portfolios. Last, we did not consider how increases in groundwater withdrawal in some parts of the country may be able to offset the effects of groundwater depletion in other parts of the country. For example, studies have suggested that eastern India (i.e., Bihar, Jharkhand, Odisha, and West Bengal) may be able to become the future bread basket of India as groundwater in this region has not been overexploited, and tube well infrastructure can be further developed. We find, however, that during the time period of our study, while area under groundwater irrigation increased in eastern India, we did not see an associated increase in winter cropped area . This suggests that, to date, increased groundwater irrigation in eastern India has not compensated for groundwater losses elsewhere, although it is possible that it may do so in the future, especially in states that are heavily investing in groundwater infrastructure such as Bihar. Our scenario analysis should be interpreted as an estimate of the maximum impact of future groundwater depletion and the maximum effectiveness of a canal expansion policy. Thus groundwater

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can be saved by alternative cropping system with optimized management practices hence enhancing environmental stability[27]

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