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Optimal Crop Planning for Economic and Ecological Sustainability of Punjab Agriculture

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Abstract: The use of natural resources in Punjab, especially irrigation water for agriculture, is facing a crisis. A proper and sustainable plan is needed for reasonable use. Therefore, the current study has been conducted to develop optimal crop plans by incorporating technologies such as wheat sown by using happy seeder (HS), direct-seeded rice (DSR), and short-duration varieties (SDVs) of paddy. The result revealed that for optimum utilization of available resources, the area under paddy, guar, and potato crops needs to be reduced while the area under basmati, sugarcane, cotton, barley, sunflower, and peas needs to be increased. By adopting the optimal plan with existing resource use and technologies the returns can be increased by 2.52%, while adoption of the optimal plan with technologies (HS, DSR, and SDVs) increased returns ranging from 3.38 to 8.63%, along with saving in irrigation water use ranging from 4.65 to 4.96%. Further, the optimal plans will help in increasing the use of underutilized human labour, and reducing the use of chemical fertilizers with presently much higher use than the recommended levels.

Keywords: Resources, Agriculture, Sustainability, Technology, Optimal plan, Returns

Resources including water, soil, plants, animal diversity, renewable energy, climate, vegetation, ecosystem, etc. are the most important affective factors in the agricultural production. Due to overexploitation, these resources are diminishing continuously. Sustainable agriculture focus on long-term production, with the least impact on the environment (Pagliarino et al 2020). The situation demands food security and improvement in agriculture. Development must guarantee both the growth of agricultural production and the conservation of natural resources (Robertson 2015). This means that the natural resources should be managed in such a way that food production is secured now as well as in the future. Therefore, food security is not an easy task based on quantity as well as in the continuity (Kielbasa et al 2018). Agriculture is forced to find a balance between conservation and development. Responsible use of natural resources is essential for agriculture. The most important of these natural sources on which existence depends are water and soil (Wrachien 2002). The future of living beings and agricultural production systems is at stake due to continuously depleting aquifers and increasing pressure on underground water under projected climate change scenarios (Kumawat et al 2020). Anthropogenic and adverse natural activities are the major factors for the deterioration of natural resources. Increased exploitation of groundwater results in depletion of groundwater level. Hence, the holistic management of water and soil resources is indispensable for agricultural sustainability as well as for the protection of the natural ecosystem. Development and adoption of improved technologies, judicious use of natural resources, and effective management practices are the need of the hour for the protection of water and soil from degradation (UNDP; FAO; WHO; WB, 2008).

India is the largest consumer of groundwater in the world, consuming more than 25% of the world's fresh water, and using 88% of it for irrigation. Much of its agricultural production depends on excessive water consumption, and production areas are likely to face water shortages in the long term. Currently, about 60% of the country's underground aquifers are under severe stress (World Bank 2009, 2010, and 2012) and the water table in the "Indus Basin" is the second most stressed in the world. Groundwater is used indiscriminately, and due to the overexploitation of water resources, the sustainability of existing agricultural systems becomes questionable and creates critical problems for the second generation (Vatta and Taneja 2018). Over-dependence and over-exploitation are particularly severe in Punjab state (North-West India) or the Green Revolution Belt (Hira 2009). The central government's policy played a key role in imitating the policy of the Green Revolution under which the pattern of agricultural production in Punjab shifted crucially towards a monoculture of paddy and wheat, the food items being important for the national goal of self-reliance in food availability (Singh 2012). Much of its agricultural production depends on excessive water consumption, and production areas are likely to face water shortages in the long term (Grover et al 2017). With a significant change in the pattern of cultivation over the last sixty years, the area devoted to the main crops increased from 3.79 in 1960-61 to 7.830 million hectares in 2020-21, an increase of over 100%. More importantly, the wheat area increased from 1.39 to 3.53 million hectares (Increase of 2.54 times). The rice area increased from 230 thousand to 3.149 million hectares (Increase of 13.7 times) during this period (Anonymous 2021). Therefore, these two crops dominated the state cultivation pattern. The mastering of paddy-wheat rotation has brought Punjab from excess water to a deficit water state. Although paddy was not the traditional crop of Punjab, oilseeds and pulses have been practically wiped out. The management of paddy straw raises significant human and soil health concerns. The studies show that the agricultural sector in Punjab has been overcapitalized and is at a stage where its inputs are being used more or less exclusively. As a result, agricultural production costs have grown and farmers now bear an extra financial burden which makes agriculture unsustainable. Therefore, a key objective of this study is to develop optimum crop plans under various technologies.

MATERIAL AND METHODS

Data: The current study is based on data collected under the 'Comprehensive scheme for studying the cost of cultivation of principal crops in Punjab' operational in the Department of Economics and Sociology at Punjab Agricultural University, Ludhiana. It is the most important database on the cost of cultivation of major crops in the state. For the present study, the data pertains to the year 2018-19. The plot-wise data were collected from the 300 farmers of 30 villages, from the three agro-climatic zones of the state, representing all the climatic conditions, farmer categories, and crops of Punjab. Besides, data from secondary published sources were also used to determine the resource use coefficients and availability levels in the state.

Analytical tools: The budgetary analysis has been performed to work out the economics of different crops. The optimum crop plans were developed using the linear programming technique. The various components in the cost of cultivation of crops under study were estimated in line with the methods provided in the manual of cost of cultivation like farm-produced and purchased seed, fertilizers and manures, plant protection chemicals, human labour, owned/hired machinery charges, and interest on working capital. Based on the cost concept used; the overall costs included the farmers' paid-out expenses in cash and kind for various items of cost of the cultivation (INR per hectare) taken in the present study. Variable cost: i) value of the seed, ii) value of fertilizer and manure, iii) value of plant protection chemicals, iv) value of human labour (family + hired), v) value of machine labour (owned + hired), vi) value of irrigation charges.

Mathematical specifications of the model: The mathematical technique of linear programming (LP) is frequently used to assist in decision-making when allocating areas under various crops and selecting various enterprise combinations. It is a simple and applicable tool for comparing various uses of scarce resources under changing goals and limitations. The program also enables to simulate the impact of different options. Using a quasi-dynamic LP model, various crop business strategies were created for the current study. The goal was to maximize returns while keeping in mind the limitations of arable land, human labour potential, irrigation water use, chemical fertilizers, and working capital. Equations 1-7, which are followed by an explanation of each, have been used to mathematically express the model explanation for optimizing.

Objective function:

$$Max\ Z = \sum_{c=1}^{n}(Y_c P_c - C_c)A_c \qquad (1)$$

Where:

Z = Returns over variable costs

Y_c = Yield of main product & by-product (per hectare) of crop species c

P_c = Price of crop output (main product & by-product) (INR per unit of crop produce)

C_c = Cost of cultivation (INR per hectare)

A_c = Area under crop species c

c = Crop species

n = Number of crop species

Area constraint:

$\Sigma_t \Sigma_c A_{tc} \leq NS_t - 0A_c$ (2)

Minimum area constraint:

$A_c \geq min_c$ (3)

Maximum area constraint:

$A_c \geq Max_c$ (4)

$A_c \geq 0$

Where:

A_{tc} Area occupied by crop species c in the t^{th} month

NS_t Net sown area

OA_c Area under orchard and other perennial crops

c Crop species

t Time (months of the year)

A_c Area under crop species c

Labour constraint:

$\Sigma_t \Sigma_c HL_{tc} \leq THL_t$ (5)

Other input constraints:

$\Sigma_c X_c A_c \leq CUX$ (6)

$A_c \geq 0$ (7)

Where:

HL_{tc} Monthly human labour use (per hectare)

THL_t Total human labour use in the t^{th} month

X_c Input use per crop (i.e. working capital, ground water, and fertilizers)

A_c Area under crop

CUX Availability of working capital, ground water, and fertilizers

Almost the entire cropped area in Punjab is under irrigation water use. Usually, crops in the state are grown in three seasons: (i) monsoon, also called *kharif* (Starts from July to October), (ii) winter, also called *rabi* (November to March), and (iii) summer (March to June). The principal crops grown during the *kharif* season are paddy, cotton, and maize, while other crops like like pigeon pea, cluster bean, green gram, groundnut, and black gram are also cultivated in a smaller area. In the *rabi* season, wheat, potato, and mustard are the major crops, whereas gram, sunflower, lentil, and barley are some of the traditional crops grown on a very small area in the state. Moong is also grown in the short window of 50-70 days during summer, also called zaid season. In this model, 20 crop activities were included. Crop and enterprise planning using LP primarily takes the supply-side behavior, more precisely, the area response based on net returns and resource constraints, ignoring the demand aspects. As a result, such models tend to overestimate or underestimate the area allocations for some crops. While the per-unit requirement coefficients of labour, working capital, farm power, and fertilizer were estimated using data from the cost of cultivation, the per ha requirement of irrigation water for various coefficients was calculated using the approach suggested in earlier studies (Cooper et al 2011, Srivastava et al 2015, Pojara and Shahid 2016, Pushpa et al 2017, Kaur et al 2018, Gill et al 2018, Anonymous 2019, Latif et al 2020, Singh et al 2022 and Bhatt et al 2022). The resource availability was mainly based on three different data sources. In the case of land, the net sown area (excluding area under perennial crops) was considered the total available land resource, whereas the number of cultivators and agricultural laborer was used to estimate the total labour availability in the state. Since the existing use of working capital and fertilizers in Punjab is already on the higher side, the use of these resources under the existing cropping pattern forms the right-hand side of the constraint equations. The minimum and maximum areas that should remain under different crops were determined based on experts' advice as well as previous area cultivation.

RESULTS AND DISCUSSION

The results of the optimal plan developed under existing resources use and technologies suggested that the total gross cropped area under wheat crop in the *rabi* season needs to be the same level 3.53 million hectares (Table 1). The area under paddy and guar in the *Kharif* season should be decreased to 2.25 million and 10 thousand hectares from 2.743 million and 33 thousand hectares and shifting to basmati, cotton, and sugarcane. The area under sunflowers, peas, and barley should be increased by decreasing the area under vegetable crops like potatoes from 107 to 60 thousand hectares, the reason is that will help to be self-sufficient for edible oils, however unforeseen rainstorms during harvest can occasionally cause problems, and peas increase from 43.9 to 50 thousand hectares. The model suggests increasing the gross cropped area (GCA) from 7.385 to 7.505 million hectares. The cropping intensity under the existing optimized model will increase to 196.83 from 193.68%. With the same level of irrigation water use, following this plan, the returns over variable cost would increase by 2.52%.

The optimized plan developed using technology wheat sown with Happy Seeder suggests sowing 741 thousand hectare of the current wheat area with Happy Seeder. The plan has suggested increasing the area under cash crops like cotton (Increased from 251 to 273 thousand hectares), and sugarcane as well as doubling the area under basmati paddy while decreasing the area under paddy by 12%. This is in line with the state's draft agricultural policy, which calls for switching 1.2 million hectares from rice to less water-intensive crops like maize, cotton, sugarcane, pulses, oilseeds, fruits, and vegetables (Vatta and Taneja 2018). The area under *kharif* and *rabi* pulses remains the same under the optimum plan. The area under *rabi* oilseeds; sunflower increased by 104% from the current area allocation and will be a good step towards making the state self-sufficient for edible oil. The area under peas and barley also increase by decreasing area under potato and with the existing irrigated water use, the returns over variable cost would increase by 3.38% in the state.

The optimum crop plan developed in wheat by introducing activity viz. sown with happy seeder (HS) and direct seeding of rice (DSR) recommend that 21% of wheat should be cultivated using Happy Seeder technology. Like other plans, this plan also suggests decreasing the area under paddy and guar while increasing the area under basmati and sugarcane during *kharif* season. The government should make arrangements for the export of basmati and ensure timely payment for sugarcane. Further, this plan suggests that out of the total recommended area for paddy cultivation, around 7% should be cultivated using DSR technology. The plan also advocates bringing more area under sunflower, which will be a good step towards self-sufficiency of the country for oilseeds and crop diversification. The government may further encourage the farmers to bring more area under oilseed crops by providing a competitive price. It can increase returns by 3.73% along with some saving in irrigation water use. The optimal plan developed with technology HS and short-duration varieties for paddy recommends beside same area under wheat with HS. As per the optimum plan the total area under paddy needs to be decreased from 2.743 to 2.430 million hectares and further out of the area 1.25 million hectares should be under short duration varieties (PR 121 and PR 121) developed by the Punjab agricultural University. The area under basmati paddy should be increased from 406 to 862 thousand hectares, while the area under sugarcane should be increased from 89 to 121 thousand hectares. This will help in saving the irrigation water to the tune of 4.65%. By adopting the recommendations of this plan, the returns can be increased by more than 8% and save 4.65% irrigation water along with saving on electricity used for running electric tube wells for irrigation. The subsidy amount saved from electricity may be utilized by the government for developing infrastructure for agriculture.

The developed optimal plan with all the technologies taken together (i.e. wheat sown with HS, paddy cultivation using DSR technology and SDVs) suggests 741 thousand

Table 1. Existing area vis-à-vis area under optimal plans, Punjab

(000'ha)

Crop category	Crops	Current area	Area under existing optimal plan	Optimum area under technology HS	Optimum area under technologies HS and DSR	Optimum area under technologies HS and SDVs	Optimum area under all technologies
Rabi Cereals	Wheat	3530	3530	2789.4	2789.4	2789.4	2789.4
	Wheat (HS)			740.6	740.6	740.6	740.6
	Wheat total	3530	3530	3530	3530	3530	3530
	Barley	5.9	12.6	12.6	12.6	12.6	12.6
Kharif Cereals	Paddy	2743	2251.4	2408.5	2265	1180	1015
	Paddy DSR				165*		165
	Paddy PR121					625	625
	Paddy PR126					625	625
	Paddy total	2743	2251.4	2408.5	2430	2430	2430
	Maize	108	108	108	108	108	108
	Basmati	406	862	862	862	862	862
Kharif pulses	Arhar	2.6	2.6	2.6	2.6	2.6	2.6
	Guar	33.3	10.2	10.2	10.2	10.2	10.2
	Moong	24.1	24.1	24.1	24.1	24.1	24.1
	Urad	2.0	2.0	2.0	2.0	2.0	2.0
Rabi pulses	Gram	2.0	2.0	2.0	2.0	2.0	2.0
	Lentil	0.6	0.6	0.6	0.6	0.6	0.6
*Rabi o*ilseeds	Rapeseed & Mustard	31.6	31.6	31.6	31.6	31.6	31.6
	Sunflower	2.5	5.1	5.1	5.1	5.1	5.1
Kharif oilseeds	Groundnut	1.5	1.5	1.5	1.5	1.5	1.5
Vegetables	Potato	107.1	60	60	60	60	60
	Peas	43.9	50	50	50	50	50
Cash Crops	Cotton-BT	251.6	430.2	273.1	251.6	251.6	251.6
	Sugarcane	89.3	121	121	121	121	121
Net Sown area (NSA)		4127	4127	4127	4127	4127	4127
Gross cropped area (GCA)		7385	7504.8	7504.8	7504.8	7504.8	7504.8
Irrigation water use (BCM)		29.06	29.06	29.06	29.03	27.71	27.62
Cropping Intensity (CI) (%)		193.7	196.8	196.8	196.8	196.8	196.8
Returns over variable cost (₹ Billion.)		483.7	495.9	500.0	501.7	523.9	525.4

hectares wheat area under the technology happy seeder in the rabi season. This plan recommends that the total area under paddy should be 2.430 in place of the current 2.743 million hectares. Further, out of these 2.430 million hectares 165 thousand hectares should be sown directly using DSR technology and for 1.250 million hectares short duration variety (PR 121 and PR 126) seed should be used. This will help in saving 4.96% of irrigation water. The optimum plan advocates increasing area under basmati, cotton, and sugarcane which is released from paddy cultivation. Also, the area under vegetables (potato) should be decreased from 107 to 60 thousand hectares and should increase the area of sunflower from 26 to 51 thousand hectares. Achieve cropping intensity of 196.83% and following the GCA to increase from 7.385 to 7.505 million hectares. This would result in increasing their returns over variable cost by 8.63% in the state.

Changes in resources use, and income: The optimum crop plans are capable of saving irrigation water ranging from 0.10 (0.03 billion cubic meters) to 4.96% (1.44 BCM) (Fig. 1) and will help in restricting the downward movement of groundwater level and ultimately helps in making agriculture sustainable. By encouraging the farmers to adopt these plans the government can save a significant amount of subsidy to be spent for providing free electricity to run the tube-wells. With the saved amount the farmers can be compensated either by providing subsidies on other inputs or by increasing the price of other competing crops. In terms of returns, the increase will be from 2.52 (INR. 495.87 billion) to 8.63% (INR. 525.42 billion) as compared to the current returns (INR. 483.69 billion) in existing resources use and technologies. Among the developed optimum plans, technologies of HS, DSR, and SDVs together were found to be more responsive to saving irrigation water use as well as the increase in returns over variable cost.

On the other hand, these plans use relatively higher human labour ranging from 0.3 to 8.57% as compared to their current usage level which is underutilized, and also working capital is increasing from 1.09 to 1.49% (Fig. 2).

These plans, if adopted, will also reduce the use of chemical fertilizers having current usage quite higher than the recommended levels. By adopting optimal crop plan

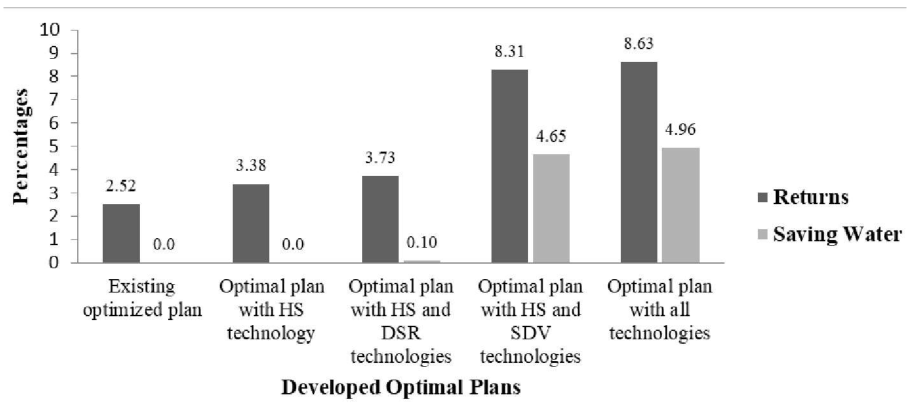

Fig. 1. Changes in existing irrigation water use and farmers' income under various developed optimal plans in Punjab

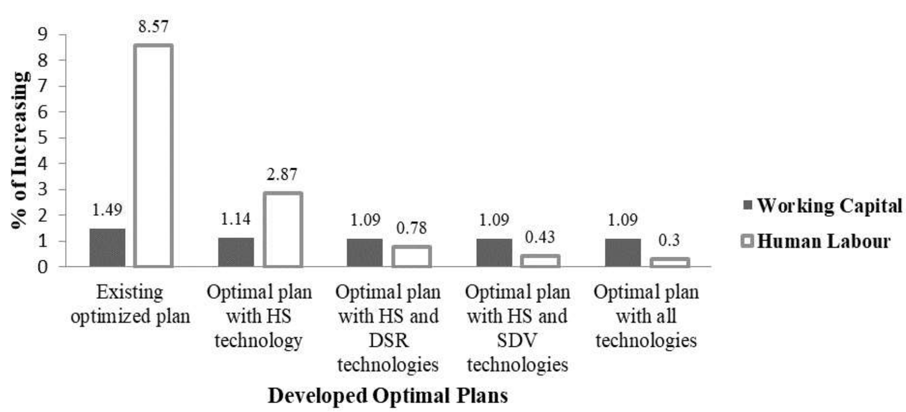

Fig. 2. Changes in existing human labour, and working capital under various developed optimal plans in Punjab

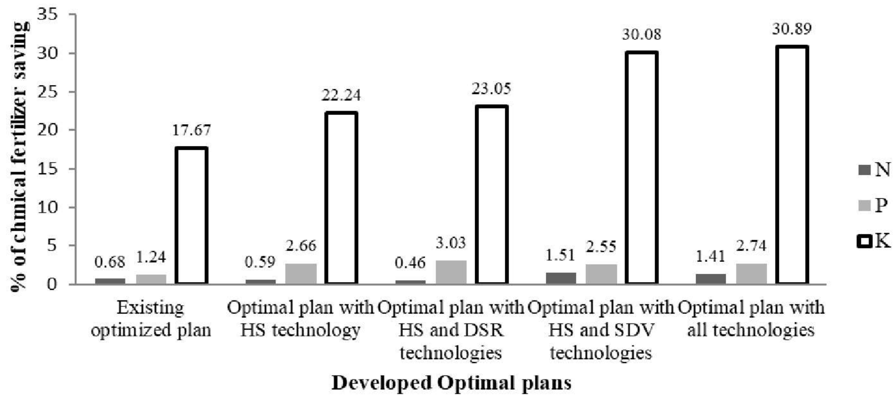

Fig. 3. Changes in the existing level of chemical fertilizer use under various developed optimal plans in Punjab

developed at existing technology level the use of N, P and K fertilizers can be lowered by 0.68, 1.24 and 17.67%, respectively from its existing use. Further, the optimum plan developed by incorporating technological interventions (happy seeder for wheat sowing, DSR and short duration varieties for paddy) the usage of N, P and K fertilizers can be reduce to the extent 1.41, 2.74 and 30.89%, respectively.

CONCLUSION

The natural resources the agriculturally advanced states of Punjab are declining at a fast rate due to intensive cultivation. In the alternative crop plan developed with existing resources use and technologies, for optimum utilization of available resources, the area under paddy, guar, and potato crops needs to be reduced while the area under basmati, sugarcane, cotton, barley, sunflower, and peas needs to be increased. Adopting the optimal plan with existing resource use and technology increases cropping intensity, and returns, while adoption of the optimal plan with technologies (HS, DSR, and SDVs) besides increasing the returns also saves irrigation water and ultimately saves electricity used for running electric tube wells. The subsidy amount saved from electricity may be utilized by the government for developing infrastructure for agriculture. Also, these plans advocate bringing more area under oilseed which will be a good step towards self-sufficiency of the country for oilseeds and crop diversification. The government may further encourage the farmers to bring more area under oilseed crops by providing competitive prices. So, if the Punjab farmers adopt these alternative crop plans, they can utilize more human labour which is largely underutilized. The crops in these optimum plans will require less quantity of chemical fertilizers that are presently having quite higher than the recommended levels, reducing the cost of cultivation along with a positive impact on the environment. These plans, if adopted by the farmers, along with saving precious groundwater will also help in increasing their income from farming.

REFERENCES

Anonymous 2019. Fostering prosperity for all, Economic and Statistical Organization Government of Punjab-1: p 125.

Anonymous 2021. Statistical Abstract of Punjab, Chandigarh. Economic Advisor to Government, Punjab State p 960.

Bhatt R and Singh P 2022. Farmer's field evaluation of direct seeded rice vis-à-vis puddled transplanted rice in Kapurthala, Punjab. *Indian Journal of Extension Education* **58**(2): 42-46

Cooper W, Seiford LM and Zhu J 2011. *Data Envelopment Analysis: History*, Models, and Interpretation. University of Texas, USA. p 39.

Gill G, Kumar S, Singh S and Bhullar MS 2018. Agronomic and economic impacts of direct seeded rice in Punjab. *Agricultural Research Journal* **55**(2): 236-242

Grover DK, Sing JM, Kaur A and Kumar S 2017. State agricultural profile, Punjab. Department of Economics and Sociology, PAU. AERC study-44: p 80.

Hira GS 2009. Water management in northern states and the food security of India. *Journal of Crop Improvement* **23**(2): 136-157

Kaur M, Singh S, Singh J, Singh JM, Kingra HS and Sachdeva J 2018. *Executive brief district-wise cost of cultivation of important crops in Punjab*, Department of Economics and Sociology, Punjab Agricultural University, Ludhiana.

Kielbasa B, Pietrzak S, Ulen B, Drangert JO and Tonderski K 2018. Sustainable agriculture: The study on farmers' perception and practices regarding nutrient management and limiting losses. *Journal of Wat and Land Development* **36**(3): 67-75.

Kumawat A, Yadav D, Samadharmam K and Rashmi I 2020. Soil and water conservation measures for agricultural sustainability, pp 4-6. In: Shrama VK and Singh D (eds). *Soil Moisture Importance*. ICAR, Delhi, India.

Latif M T, Hussain M, Faisal N, Ullah S, Zafar U, Rafiq H M, Rehman A, Asghar, Ahmad I, Hamid and Hussain I 2020. Economics of wheat production with happy seeder in rice-wheat cropping system of Punjab, Pakistan. *Global Scientific Journal* **8**: 2320-9186

Pagliarino E, Orlando F and Vaglia V 2020. Participatory research for sustainable agriculture: The case of the Italian agro-ecological rice network, *European Journal of Futures Research* **8**(7): 166-169.

Pojara M and Shahid A 2016. Crop diversification: Challenges of switching crops in Punjab. *Indian Journal for Economics Development* **12**: 575-578.

Pushpa, Srivastava SK and Agarwal PK 2017. Comparative study on cost of cultivation and economic returns from major crops in eastern region of Uttar Pradesh. *International Journal for Agricultural Environment and Biotechnology* **10**(3): 387-399.

Robertson GP 2015. A sustainable agriculture? *Journal of the American Academy of Arts & Sciences* **144** (4): 76-89.

Singh P 2012. The role of externally governed economic policies in shaping Punjab's agrarian oriented development pattern. *Journal of Agricultural Development & Policy* **22**: 1-18.

Singh JM, Sachdeva J, Bhangu PKS, Singh J, Kaur B and Kumar H 2022. Groundwater saving in Punjab: Role of short duration paddy varieties in agricultural sustainability. *Indian Journal of Ecology* **49**(2): 358-362.

Srivastava SK, Chand R, Raju S, Jain R, Kingsly I, Sachdeva J, Singh J and Kaur AP 2015. Unsustainable groundwater use in Punjab agriculture: Insights from cost of cultivation survey. *Indian Journal of Agricultural Economics* **70**(3): 365-378.

UNDP/FAO/WHO/WB 2008. *Agriculture at a Crossroads*, International Assessment of Agricultural Knowledge, Science and Technology for Development, Washington DC, USA, p 606.

Vatta K and Taneja G 2018. *Water energy agriculture nexus in India: A case study of Punjab*, USAID and Centers for International Projects Trust New, New Delhi, India, p 77.

World Bank 2009. *Beyond economic growth an introduction to sustainable development,* Washington, D.C. 20433, USA, p 280.

World Bank 2010. *World Development Indicator*, Washington, D.C. 20433 USA, p 489.

World Bank 2012. India groundwater: A valuable but diminishing resource, (See in the web: https://www.worldbank.org/en/news/feature/2012/03/06/india-groundwater-critical-diminishing)

Wrachien D 2002. Land use planning: A key to sustainable agriculture, pp. 1-15. Institute of Hydraulics Agricultural State University of Milan, Italy.

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