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Assessing the sustainability of vegetable production in India

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Abstract

Vegetable production is an important constituent in Indian agriculture and has a vital role in achieving nutritional security. Factors such as perishability, high value and good yield response to external inputs has led to intensification of vegetable production. Measuring the sustainability of vegetable production and factors influencing it by employing suitable indicators will be helpful in designing of policy instruments and production practices for economically viable and environmentally sustainable production. Thus, the present study was designed to assess the plot level sustainability in Karnataka, a major vegetable growing state in India. Both the economic and environmental sustainability scores were low, proving the existence of ample opportunity to improve the sustainability of the vegetables in the state. Overall composite sustainability indicator for the economic pillar had better accomplishment than the environmental pillar for both the vegetables. The results show that the size of the holding, preference for higher incomes, years of experience in growing vegetables had significant and positive impact on economic sustainability. Flood irrigation decreases the economic sustainability in comparison to rainfed farming system. The low scores of sustainability reflects the crucial role of farmers' productive decisions, which finally Determine the level of sustainability of each individual farm. Thus, there is room to incentivize producers to modify the way they manage their resources through appropriate policy instruments in order to upgrade their sustainability performance.

JEL Codes: N5, O13, Q01

1. Introduction

Horticulture is a prominent sub sector in Indian agriculture and is growing faster compared to other sub sectors (Vanitha et al. 2013). Vegetable production is an important constituent in Indian agriculture and has a vital role in achieving nutritional security. It has now become a remunerative farm enterprise, sustaining the livelihood of most of the marginal and small farmers in rural and peri-urban areas (Rao and Joshi 2009). India has become the second largest producer of vegetables in the world next to China (Horticulture statistics at a glance, 2018). Increase in health consciousness and purchasing parity of people have spurred the demand for more nutritious and healthy diet including fruits and vegetables. On the supply side, as a result of technological advancements, vegetable production has become economically viable occupation for even for small and marginal farmers in India (Rao and Joshi 2009).

Factors such as perishability, high value and good yield response to external inputs has led to intensification of vegetable production. However, the sustainability of such practises is a question. This intensification and specialization process creates shifts in the local farming systems (Birthal et al, 2007). The crop risk level is higher in intensive vegetable production because of agrochemicals, which is very limited in traditional and subsistence farming. Inaccessibility of affordable technologies and insufficient work force with good technical knowhow are the major challenges of horticulture in developing countries (Xu 2022). As a result of growing global challenges in the form of population, environmental degradation, climate change and civil conflicts, country such as India has to be ready for achieving sustainable development in horticulture sector (Bakshi et al. 2022).

The definition of Sustainable development itself is evolving ever since the Brundtland definition was put forth (Brundtland, 1987). Sustainability in Agriculture is multifaceted notion and there is no common viewpoint among scholars about its dimensions (Hayati *et al.* 2010). It can be measured at the global, regional, national, farm levels or plot level. Several literatures have strongly encouraged assessment of sustainability at the farm level to ensure accuracy for the decision-makers (Reed and Doughill, 2003, Pretty 1995). The importance of assessment of systems sustainability jointly by a set of indicators as opposed to single indicator has been emphasised by many scholars (e.g. Niemeijer and Groot, 2008, Lyytimäki and Rosenstrom, 2008). The present study hence is based on composite indicator measuring economic and environment sustainability at farm or plot level.

Measuring the sustainability of vegetable production and factors influecing it by employing suitable indicators will be helpful in designing of policy instruments and production practices for economically viable and environmentally sustainable production. Thus, the present study was designed to assess the plot level sustainability in Karnataka, a major vegetable growing state in India. Onion and tomato were opted as they cover more than 50 per cent of vegetable area of the state (Afrin et al. 2020) were selected.

2. Material and methods

Multi-stage random sampling framework was adopted in selection of study area. Karnataka state was purposefully selected, as it is one of the major vegetables growing states contributing about five per cent to the total countries production. Among the vegetables, tomato and onion had been selected for this study, as they together contribute to more than 50 per cent of the total area under production of vegetables.

Further, Chitradurga district in Central Dry Zone and Kolar district in Eastern dry zone of Karnataka were selected purposefully based on area and production of vegetables. Chitradurga district could be considered as the foremost district concerning onion production, since it has the second largest area under onion production with 35361 hectares and the largest producer with 699463 tons of production, with productivity of 19.78 tons per hectare. Kolar has the highest area as well as productivity of tomato*, ie.,* 8712 ha and 57.06 tonnes per ha.

2.1 Sampling framework and data sources

The primary data was collected from a random sample of 120 farmers, 60 farmers each for onion and tomato from Chitradurga and Kolar districts, respectively during 2018-19. Primary data was collected using a pretested schedule, which included details on the background information of farm family, information on costs and returns of crops of onion/tomato, agronomic and plant protection practices followed, risk and risk management, and finally opinion of farmers regarding the sustainable practices.

2.2 Sustainability measurement framework

To assess the economic and environmental sustainability, system-based indicators approach was employed. Depending on the suitability and availability of data type, economic sustainability was measured at performance stage and environmental sustainability was assessed at practice stage. Sustainability indicators were selected based on the renowned literatures in the field and then further refined with expert's opinion. Experts were asked rate individual indicator based on three criteria: Relevance to sustainability, measurability and policy relevance to obtain weight for their aggregation. Economic indicators were categorized into five principle which were bifurcated into nine indicators and sub-indicators wherever necessary. The five principles are economic viability, efficiency, financial independence, resilience and transferability. Similarly, Environment sustainability was measured under four dimension, namely farming practices/ input use, management of resources, organisation of space and diversity. Eleven indicators belonging to four principles were obtained and classified into sub-indicators. Individual indicator value was estimated through suitable procedure to obtain their crude values. They were then normalized using rescaling technique to obtain comparable sustainability scores. Further, by applying the weights composite indicators value was obtained for each pillar. The detailed information on selected dimension, indicators and weights is published elsewhere (Bi AZ,).

2.3 Analysis

Beta regression model

A linear regression model does not give precise results because the scores could have continued endpoint, (0 means completely unsustainable and 1 means perfectly sustainable). To address this issue, a beta regression model, which is a generalized-linear model, was introduced (Ferrari and Cribari-Neto, 2004) the probability beta density $[y \sim B(p,q)]$ for dependent variable y is defined in its general form as:

$$f(y:p,q) = \frac{\Gamma(p+q)}{\Gamma(p)\Gamma(q)} y^{p-1}(1-y)^{q-1}, \qquad 0 < y < 1$$

Where *p* and *q* are unknown parameters controlling the shape of the distribution, *p, q*>0, *y* is a dependent variable, and Γ(.) is the gamma function. In beta regression, it is common to define shape parameters (*p, q)* of density to that of the mean (μ = *p/(p +q)*) and ϕ=*p+ q,* the probability beta distribution density of a random variable *y* with a beta distribution [*y*~ *B* (μ, ϕ)] can be written as :

$$f(y;\mu,\phi) = \frac{\Gamma(\phi)}{\Gamma(\mu\phi)\,\Gamma((1-\mu)\phi)} y^{\mu\phi-1} y^{(1-\mu)\phi-1}, 0 < y < 1$$

Where 0< μ<1 and ϕ>0. Hence the mean and the variance of the random variable *y* were defined as E(*y)*= μ (1- μ)/(1+ ϕ). For the precision parameter (ϕ) of a fixed estimate (μ). Higher the ϕ value, smaller the variance of the variable.

Assuming the percentage response variables having beta distributed, a beta regression model was employed. Let $y_1, y_2 .....y_n$ be a sample from beta density *B* (μ, ϕ) [*y*~ *B* (μ, ϕ)], the beta regression modal defined as :

$$g(\mu_i) = \beta_0 + x_{i1}\beta_1 + \cdots + x_{ik}\beta_k = \eta_i, \qquad i = 1, \ldots, n$$

Where $x_{i1},....x_{ip}$ are the covariates, $\beta_0, \beta_1,..., \beta_k$ are the estimated intercept and coefficients corresponding to each covariate, η_i is the linear predictor for the i[th] observation and *n* is the sample size. Here *g(.)* is link function, which connects the linear predictor and the response variable. The logit link was used in this study [*g*(μ)= log(μ/[1-μ])] for beta regression, performed using *betareg* in R software.

Based on the review of literature, factors influencing sustainability of vegetable cultivation were selected, which were of both qualitative and quantitative types. Size of land holding of the farmer in acres, family size expressed in numbers, age of decision maker, education level expressed in terms of the number of years of formal education, awareness about the environmental impact of production practices expressed categorically (0 for unaware and 1 for aware), years of experience in vegetable production and risk aversion behaviour of farmer (average of the seven statements on the perception of farmer related to risk). Further, availability and method of irrigation were captured using dummy variables, where the benchmark variable was rainfed farming, other dummies were for flood, drip and sprinkler irrigation

3. Results

3.1 Estimation of sustainability scores

To provide a broader picture of economic and environment sustainability indicators, statistical descriptions of the average value of composite values, calculated for onion and tomato cultivation are provided in Table 1 and Table 2. It is worth highlighting that economic sustainability scores were distributed with a mean of 0.581 and a standard deviation of 0.07 for onion and a mean of 0.616 and a standard deviation of 0.09 for tomato. Although all farms operating within a particular agricultural system share the same edaphoclimatic (crop alternatives), technological (productive options), market or legal frameworks, they can be relatively heterogeneous in terms of economic sustainability performance (see Appendix 3). Onion and tomato cultivation had composite economic sustainability indicator of as high as 0.77 and 0.85, respectively. However, the least composite economic sustainability indicator values of 0.47 and 0.42 were also observed for onion and tomato, respectively.

Dimension-wise scores of economic and environment sustainability are presented in Figure 1 and Figure 2. Farmers had better scores in productivity than in profitability, indicating the cost structures and prices required to give more importance, to improve the economic sustainability. Indicators of financial autonomy, resilience and transferability had poor performance compared to other economic indicators. It indicates the weak managerial competence among vegetable growing farmers. Normalized scores of each indicator of economic and environment sustainability is provided in Appendix 1 and Appendix 2.

Table 1: Distribution of composite economic sustainability indicators

(Percentage)

Crops	Count	Mean	SD	Min	25%	50%	75%	Max
Onion	60	58.05	7.08	47.38	52.39	57.37	61.79	77.92
Tomato	60	61.66	9.47	42.42	53.70	62.92	67.87	85.56

The two crops had peripheral differences with respect to the composite environmental indicator, with average scores of 0.47 (47 %) and 0.49 (49%) for onion and tomato, respectively (Table 2). Since the value of composite indicator is lower than sustainable path (less than 0.5) for both the crops. Castoldi and Bechini (2010) reported similar outcomes for rice cultivation, i.e., low environmental sustainability because of the poor practices adopted in pest and soil management and weak energy gain. Chand *et al.* (2014) had also come out with similar results for sustainability of dairy breeding practices, with average scores of 0.51.

Figure 2 reveals the performance of each dimension of environmental sustainability for onion and tomato cultivation. Comparing indicators of environmental sustainability between crops is more meaningful, than comparisons in economic sustainability. Tomato cultivation was comparably more environmentally sustainable than onion, as it had exhibited higher normalized scores for many dimensions over onion cultivation. organization of space and external material disposability were the only two indicators where onion had outperformed tomato.

Table 2: Distribution of composite environmental sustainability indicators

(Percentage)

Crops	Count	Mean	SD	Min	25%	50%	75%	Max

Onion	60	47.19	5.74	29.31	43.82	46.90	51.08	60.47
Tomato	60	49.45	5.42	38.50	44.86	49.85	52.42	60.80

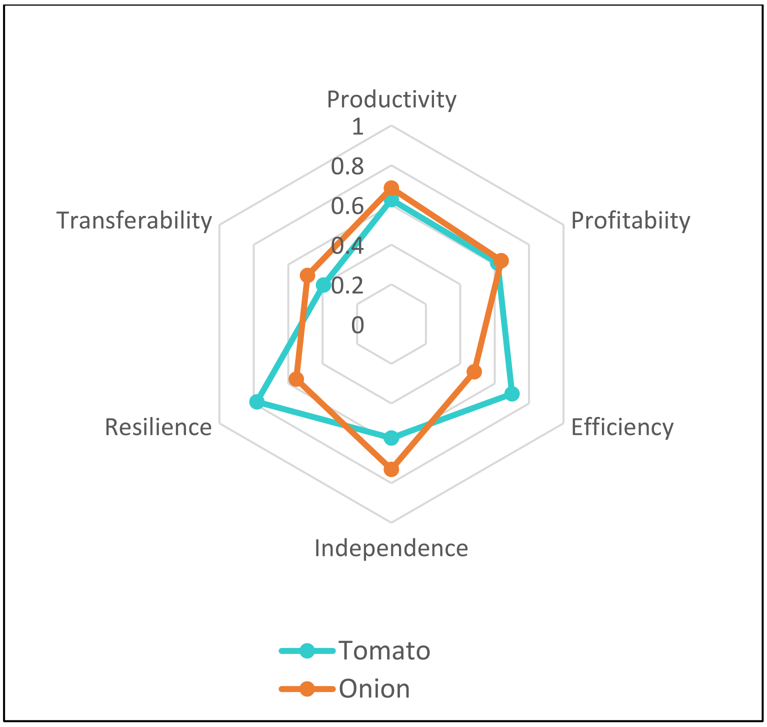

Figure 1: Economic sustainability scores of onions and tomato cultivation

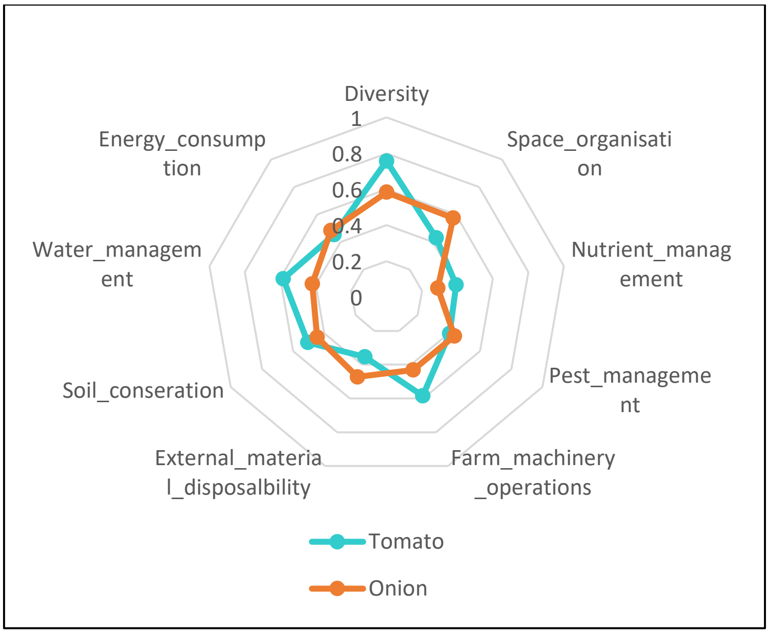

Figure 2: Environmental sustainability scores of onions and tomato cultivation

3.2 correlation between sustainability indicators

An individual farmer may face trade-offs between maximizing production in the short term and ensuring sustainable production in the short term (Hyberg & Setia, 1996). Based on the correlation analysis, we could identify the presence of synergies (i.e., movement of both the economic and environmental performance in the same direction) and those showing trade-offs (i.e., movement of the two dimensions in an opposite direction) in the enhancement of farm economic and environmental performance. The underlying intricated relations were measured with the assistance of the Pearson correlation. In line with the general notion of negative correlation between economic and environmental sustainability, results have shown the existence of trade-off between them, yet insignificant (Table 3). The reason for week negative correlation might be due to inadequate sample size. The findings of Reig-Mart´ınez *et al.* (2011), Wrzaszcz (2014) and Ryan *et al.* (2016) are contrary to the present results, which could be explained by the parabolic nature of the relationship between the two pillars. The little evidence of trade-offs between economic and environmental objectives needs to be confirmed by studies with large set of data including all major crops in the region.

Table 3 Correlation between economic and environmental sustainability scores in vegetable production

Sustainability pillars	Economic sustainability	Environmental sustainability
Economic sustainability	1	-0.079
Environmental sustainability	-0.079	1

The kind of relationship differs when the components of each pillar are studied individually. Indicators such as diversity, pest management and energy consumption had a negative significant correlation with economic indicators. However, nutrient management, water management and farm machinery operations shared positive and significant relationship with economic indicators (Appendix 5). Indicators within the same pillar exhibit a complex correlation pattern which is clear from Appendix 6 and Appendix 7. Profitability was negatively correlated with efficiency and independence. Efficiency shared positive relation with productivity and transferability. Diversity was negatively correlated with pest management and external material disposability, but positive with energy consumption. Nutrient management was correlated positively with external material disposability and negatively with energy consumption. Hence, it can be concluded that the entangled nature of relationship exists between the indicator of sustainability coming in the way of developing clear-cut plans to improve farm sustainability.

3.3 Causality analysis of sustainability indicators

Economic and environmental sustainability scores were regressed on the independent variable using beta regression, which was tailored to address continuous dependent variable ranging between 0 and 1. The explanatory variable considered for this analysis were family size, size of land holdings, production form (rainfed, flood, drip, sprinkler), education level of the farmer, environmental consciousness, years of experience in growing vegetables and risk aversion behaviour of farmer, education of the farmer.

Numerous factors can impact farms' economic and environmental performance. These factors can be classified into two categories: factors pertaining to the general environment of the farm and those related to the particular farm itself as an economic agent (Jan et al. 2011). Taking into account the variable availability and the limited sample size, we focused on the following factors for the present work: family size, size of land holdings, production form (rainfed, flood irrigation, drip irrigation, sprinkler irrigation), education level of the farmer, environmental consciousness, years of experience in growing vegetables and risk aversion behaviour of farmer education of the farm manager.

Economic and environmental sustainability scores of individual farmers were regressed to explore the cause-and-effect relationship using beta regression and the results are presented in Table 4 and Table 5. Size of the holding had significant and positive impact on impact on economic sustainability. Reig-Mart´ınez *et al*. (2011), conferred a similar relationship, but for global sustainability indictor (composite of economic, environmental and social sustainability). The fact that larger farms were more economically sustainable can be explained by the operation of economies of scale and therefore existence of greater efficiencies.

Results indicate that farmers with a preference for higher incomes (over steady returns, but potentially lower-risk ventures) had better performance in the economic pillar of sustainability. Here, production efficiency is a passive and relative notion. So, results can best be interpreted as risk-averse land managers seem to generate fewer negative impacts in vegetable production than their less risk-averse counterparts. As risk-takers tend to invest more on risky ventures in anticipation of higher returns. However, a contrary conclusion was made by Stoeckl *et al*. (2015). Lien et al. (2006) illustrated the possible conflicts existing between pursuit of risk efficiency and economic sustainability.

Further flood irrigation decreases the economic sustainability in comparison to rainfed farming system. The effect could be ascribed to the increased cost of production due to irrigation, in turn, augmented the cost of other inputs due to intensive cultivation. However, the effect of drip and sprinkler over rainfed farming was offset by the increase in efficiency and productivity, thus the co-efficient was found insignificant.

Years of experience in growing vegetables found positively and significantly affecting economic sustainability. The impact could be attributed to the increased knowledge and practical experience gained with the growing number of seasons.

Table 4. Test statistics of beta regression for economic sustainability

Variables	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	0.202	0.212	0.948	0.343
Size of holdings	0.071	0.045	-2.664	0.024*

Family size	-0.012	0.012	-1.041	0.298
Education	0.018	0.012	1.47	0.141
Flood irrigation	-0.087	0.128	-1.676	0.049**
Drip irrigation	-0.215	0.061	-3.52	0.0004***
Sprinkler irrigation	0.036	0.222	0.164	0.869
Environmental awareness	-0.105	0.106	-0.991	0.321
Years of experience in vegetable cultivation	0.008	0.004	2.226	0.026**
Risk averse behaviour	-0.174	0.095	1.82	0.068*
Pseudo R^2			0.44	

Note: ***, ** and * indicates significance at 1%, 5% and 10% levels, respectively

Environmental sustainability could be better modelled with selected explanatory variables compared to economic sustainability. It had more variable significant at a higher level and also pseudo R^2 has a higher value for the environmental sustainability model.

Unlike economic sustainability, environmental sustainability had a significant and positive association with family size, this could be attributed to the involvement of family members in decision making regarding environmentally friendly practices and availability of farm family labour to carry out operations like IPM, traditional ploughing, preparation of farmyard manure, etc. The causality further could be explained by the presence of elderly persons in the family, who influence the adoption of traditional practices of production.

Education was found significantly encouraging farmers to pay heed to environmentally friendly practices to retain and flourish the ecosystem and in turn its productivity. A comparable finding on positive association of education with adoption on sustainable agricultural practices was reported by Stoeckl *et al.* (2015), Digal & Placencia, 2019; Setsoafia et al, 2022, Giannakis, 2014; Joshi et al., 2019; Xie et al., 2015. Stoeckl *et al.* (2015), commented, it might not be feasible to expect a highly educated person to manage farms, as they tend to move out with the availability of better opportunities.

Contrary to the general notion, environment awareness was found to have no significant impact on environment sustainable production for vegetables. However, there are many literatures proving this hypothesis previously (Sriwichailamphan, 2014, Sarker et al, 2005, Tey et al. 2014)

Further, drip irrigation had a positive and significant impact on environmental sustainability over rainfed farming. Rainfed farms had less optimum diversity and rotational practices compared to the ones with drip irrigation. Their energy ratio too was lower than drip farmers, hence, drip irrigation is more sustainable than rainfed vegetable cultivation.

Number of years of experience not only enhances economic performance, but also has a positive and significant impact on environmental sustainability. Years of experience in vegetable provides better exposure to various available environmentally friendly practices such as IPM, INM. It also provides experience to understand the optimal level of inputs to use to increase production, thereby it prevents indiscriminate use of chemical inputs. Alike, Ganpat et al. (2014), Lemeilleur (2013), Vanslembrouck et al. (2002) have found positive association of years of experience with environmentally sustainable production. On the other hand, some of the studies (Sarker et al. 2005, Joshi et al. 2019 and Ullah et al, 2015) have reported no significant association in developing countries.

Considering the limitation in sample size (n=120) and data availability on general environmental and political factors Pseudo R^2 (0.44 and 0.52) for economic and environmental sustainability) was not so high, however, the finding still gives a good picture about the functioning of the sustainability performance of vegetable cultivation.

Table 5 Test statistics of beta regression for environmental sustainability

Independent variables	Estimate	Std. Error	z value	Pr(>|z|)
Intercept	-0.233	0.107	-2.17	0.029*
Size of holdings	-0.035	0.023	-1.517	0.129
Family size	0.018	0.006	3.024	0.002**
Education	0.014	0.006	2.462	0.013*
Flood irrigation	-0.078	0.064	-1.216	0.224
Drip irrigation	-0.215	0.061	-3.52	0.000***
Sprinkler irrigation	-0.017	0.111	-0.16	0.872
Environmental awareness	-0.010	0.053	-0.198	0.842
Years of experience in vegetable cultivation	0.007	0.002	3.328	0.000***
Risk averse behaviour	-0.045	0.048	0.936	0.349
Pseudo R^2			0.52	

Note: ***, ** and * indicates significance at 1%, 5% and 10% levels, respectively

4. Discussion

Vegetable production is crucial component in Indian agriculture to achieve nutritional security. Understanding the sustainability of current farming practices is key for sustainable development in vegetable production in the face of rising demands and declining land availability. Sustainability assessment is complex and multidisciplinary in nature, yet a key to plan and achieve sustainability in agriculture production. An effort has been made to measure the sustainability of vegetable production employing composite indicator for economic and environment pillar.

Both the economic and environmental sustainability scores were low, proving the existence of ample opportunity to improve the sustainability of the vegetables in the state. Overall composite sustainability indicator for the economic pillar had better accomplishment than the environmental pillar for both the vegetables. This further emphasizes the importance of reconsideration of agronomic practices followed by vegetable growers. There might be enough number of environmentally friendly research outputs emerged, yet their adoption by the farmers is still not significant.

The farmers in vegetable cultivation had better performance with respect to productivity and profitability. Yet the poor performance in other dimensions of economic sustainability hints the need for enhancing managerial competence of farmers. Thus, effort should be directed towards improving their managerial skills in addition to the technical skills.

Economic and environmental sustainability scores were modelled using beta regression. This study also concentrates on economic, social and psychological factors influencing the decision of farmers towards sustainable practices. The results show that the size of the holding had significant and positive impact on economic sustainability. Farmers with a preference for higher incomes (over steady returns, but potentially lower-risk ventures) had better performance in the economic pillar of sustainability. Flood irrigation decreases the economic sustainability in comparison to rainfed farming system. Years of experience in growing vegetables was found positively and significantly affecting economic sustainability. Environmental sustainability had a significant and positive association with family size, education level, years of experience in cultivation of particular crop. Further, drip irrigation had a positive and significant impact on environmental sustainability over rainfed farming.

The general notion of positive impact of eduction and experience in vegetable cultivation couldnot be completely accepted, as education did not show significant impact on economic sustainability. But rest of variables showed positive significant relationship. Further the hypothesis of impact of risk aversion on environmental sustainabililty is also rejected . nonethe less it showed negative impact on economic sustainabilty *ie.,* risk loving farmers had better economic sustainabilty performance.

5. Conclusion

To achieve sustainable growth in vegetable production amid increasing demands for food and shrinking land supply, combined with other global crises, it is imperative to understand level of sustainability of present cultivation practices and the causing factors. Little work has been done in India so far to quantify the sustainability at farm level. Hence this study provides the general understanding of sustainability of intensify cultivation in general and vegetable production in particular. The low scores of sustainability reflects the crucial role of farmers' productive decisions, which finally determine the level of sustainability of each individual farm. Thus, there is room to incentivize producers to modify the way they manage their resources through appropriate policy instruments in order to upgrade their sustainability performance.

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Appendix 1: Normalized scores of economic sustainability indicators of onion

Indicators	Onion		Tomato	
	Mean	SD	Mean	SD
Labour productivity	0.71	0.21	0.64	0.22
Capital productivity	0.68	0.22	0.67	0.19
Land productivity	0.67	0.23	0.57	0.30
Productivity	0.69	0.18	0.63	0.19
Gross margin	0.61	0.22	0.56	0.18

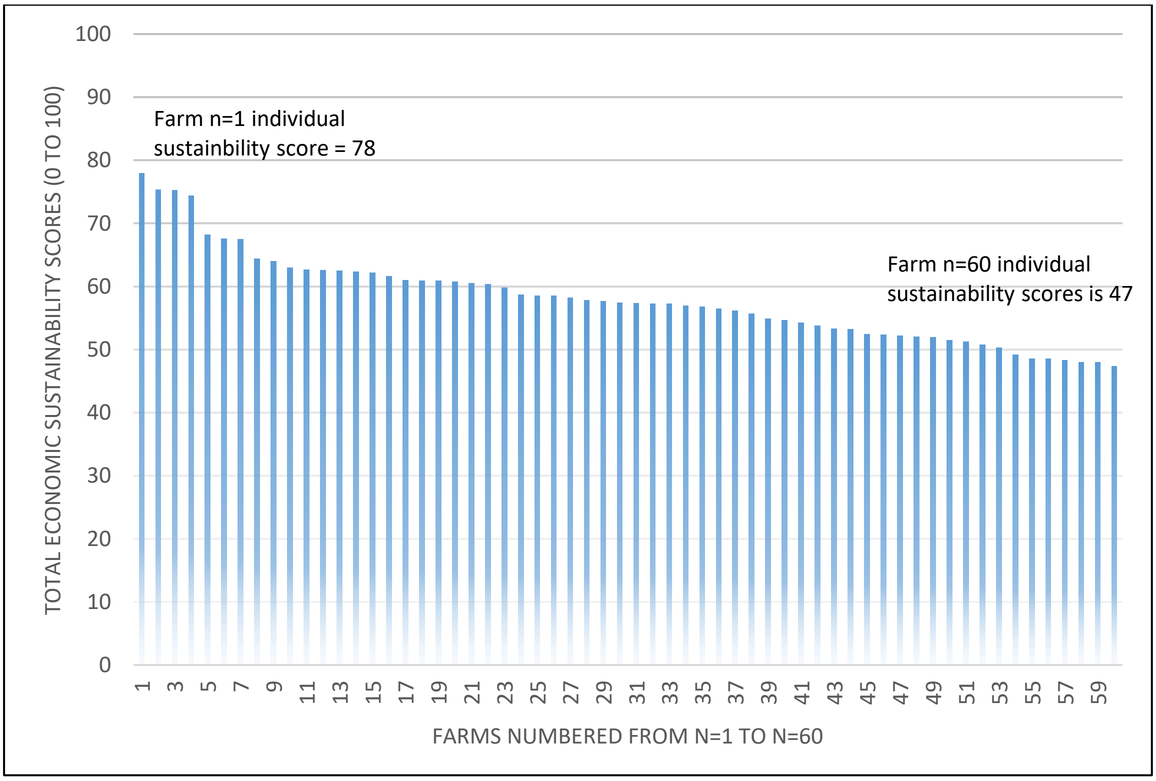
Net margin	0.59	0.22	0.56	0.18
Labour profitability	0.68	0.25	0.77	0.19
Returns on equity	0.67	0.13	0.58	0.21
Profitability	0.64	0.17	0.62	0.16
Technical efficiency	0.76	0.24	0.84	0.18
Allocative efficiency	0.39	0.27	0.69	0.17
Economic efficiency	0.30	0.26	0.58	0.20
Efficiency	0.48	0.20	0.70	0.15
Subsidy reliance-I	0.95	0.03	0.80	0.16
Subsidy reliance-II	0.95	0.15	0.96	0.17
Financial autonomy	0.20	0.23	0.27	0.26
Independence	0.70	0.09	0.68	0.13
Resilience	0.55	0.23	0.55	0.23
Transferability	0.49	0.25	0.39	0.26
Composite indicator	58.05	7.08	61.66	9.47

Appendix 2 : Normalized scores of environmental sustainability indicators of onion

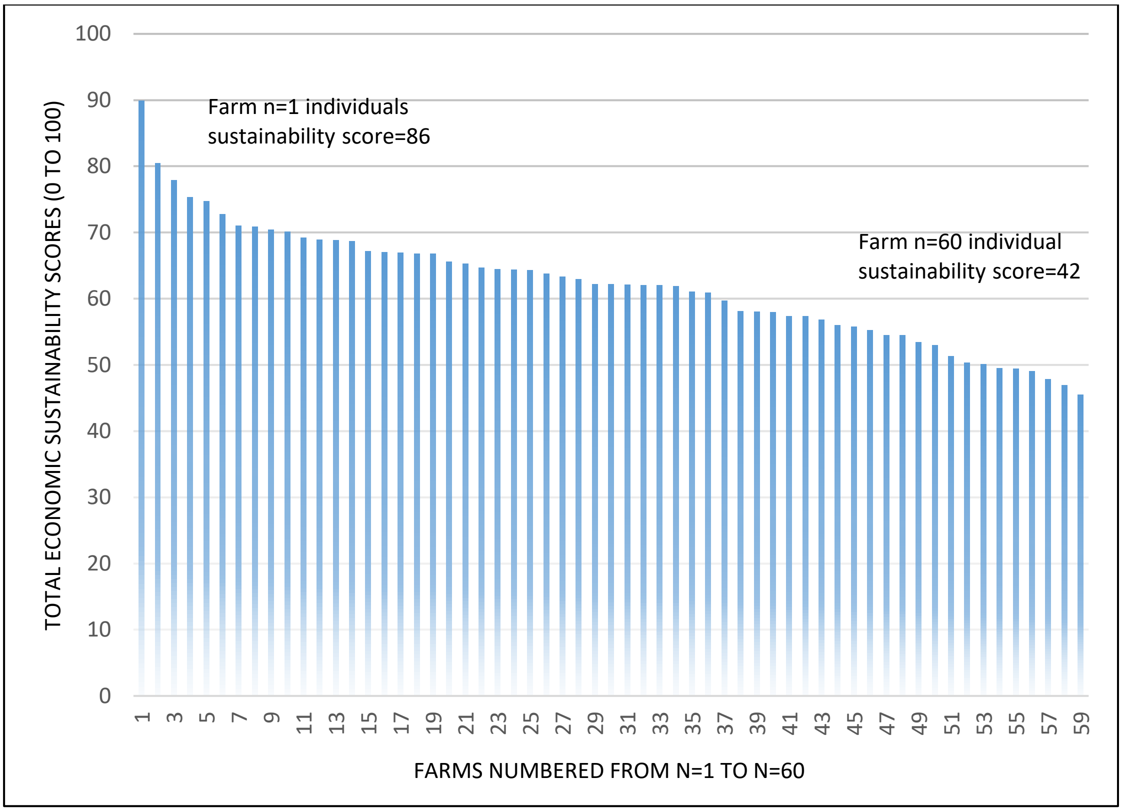
Indicators	Onion		Tomato	
	Mean	SD	Mean	SD
Crop diversification index	0.52	0.19	0.70	0.19
Genetic diversity	0.65	0.13	0.81	0.14
Total diversity	0.58	0.11	0.76	0.12
Cropping intensity	0.48	0.28	0.20	0.28
Rotation total	0.67	0.30	0.66	0.34
Space organisation	0.58	0.25	0.43	0.24
Nutrient imbalance	0.50	0.25	0.62	0.21
Organic nutrient proportion	0.45	0.27	0.44	0.25
Integrated nutrient	0.42	0.32	0.59	0.25
Organic manure	0.57	0.34	0.31	0.24
Soil test based fertilization	0.00	0.00	0.00	0.00
Nutrient management	0.38	0.14	0.39	0.07
PPC (AI)	0.48	0.26	0.36	0.26
IPM count	0.39	0.24	0.45	0.27
Pest management	0.44	0.17	0.40	0.20
Heavy machineries	0.65	0.26	0.86	0.21
Traditional plough	0.22	0.38	0.31	0.32

Farm machinery operations	0.43	0.21	0.58	0.18
External material disposal	0.47	0.26	0.35	0.28
Farming practices	0.43	0.09	0.43	0.10
Live plant cover	0.42	0.31	0.75	0.29
Silt application	0.35	0.48	0.35	0.48
Conservation tillage	0.57	0.34	0.42	0.34
Soil conservation	0.45	0.25	0.51	0.20
Water scarcity	0.51	0.28	0.52	0.33
Irrigation method	0.24	0.36	0.90	0.30
Irrigation source	0.15	0.35	0.05	0.22
Irrigation pressure	0.77	0.23	0.87	0.18
Water management	0.42	0.25	0.58	0.14
Energy ratio	0.68	0.24	0.64	0.22
Non-renewable share	0.31	0.21	0.27	0.23
Energy consumption	0.49	0.15	0.45	0.19
Natural resource management	0.45	0.08	0.51	0.09
Composite indicator	47.19	5.74	49.45	5.42

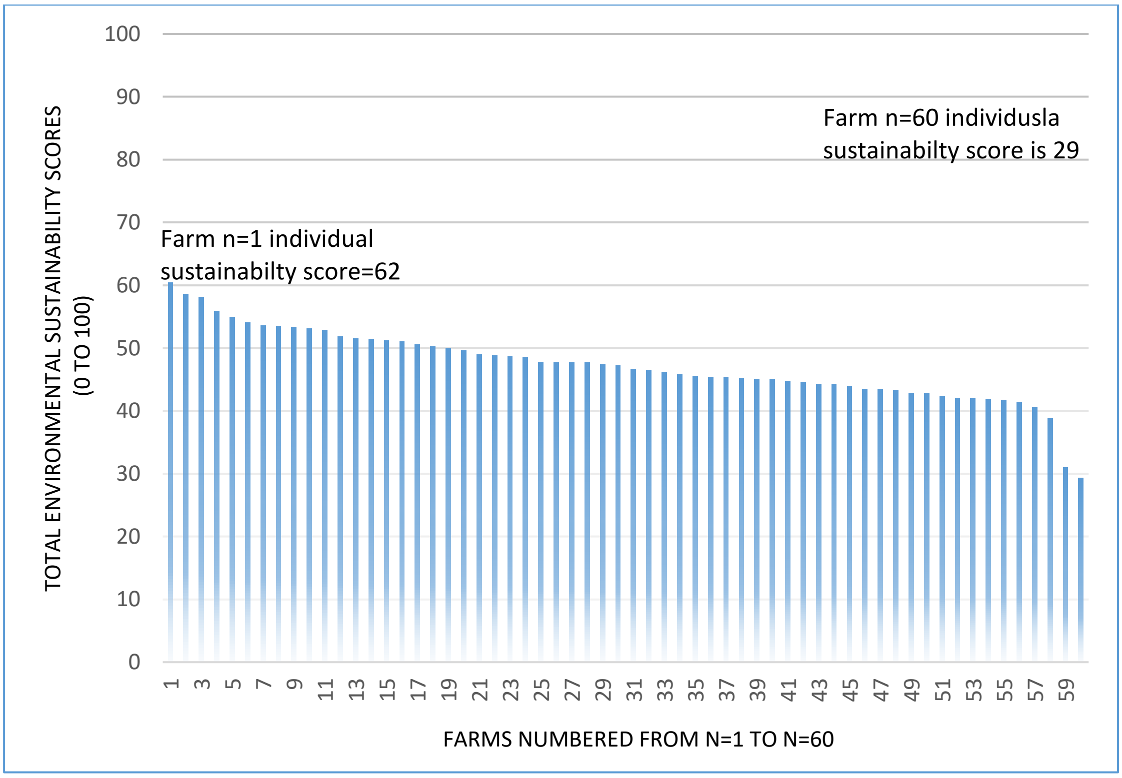
Appendix 3a: Economic sustainability scores of onion cultivation



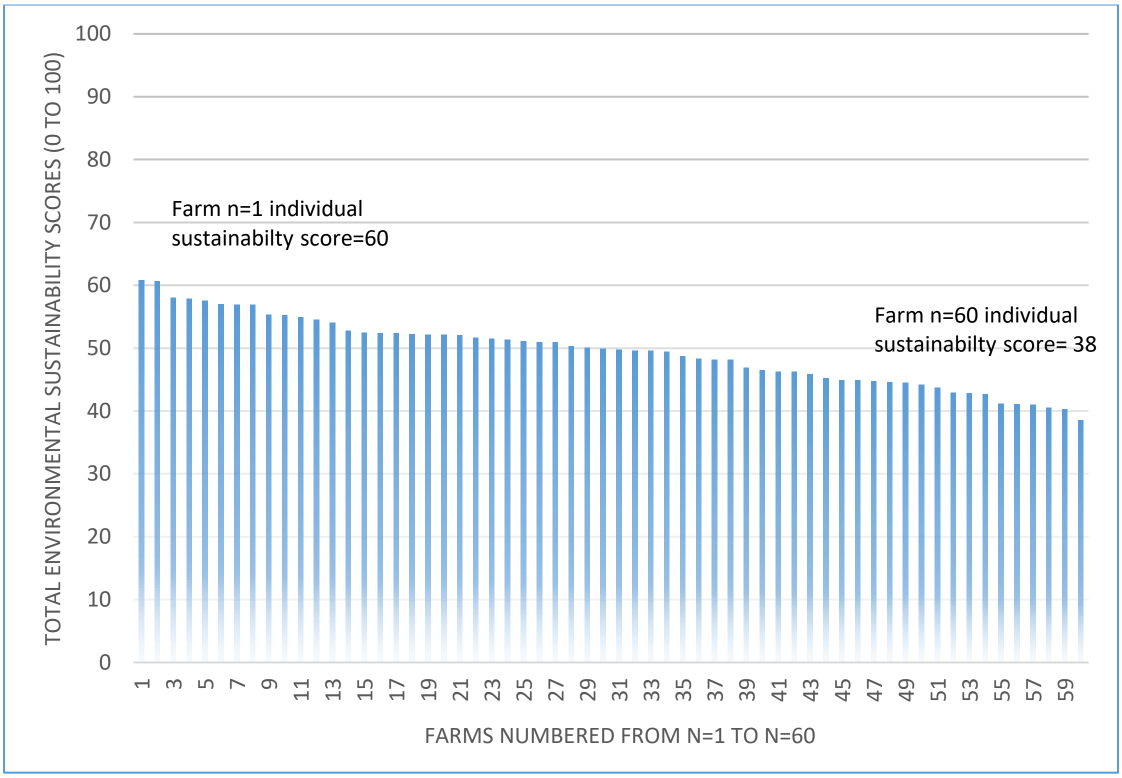
Appendix 3b: Economic sustainability scores of tomato cultivation



Appendix 4a: Environmental sustainability scores of onion cultivation



Appendix 4b: Environmental sustainability scores of tomato cultivation



TOTAL ENVIRONMENTAL SUSTAINABILITY SCORES (0 TO 100)
100
90
80
70
60
50
40
30
20
10
0
Farm n=1 individual sustainabilty score=60
Farm n=60 individual sustainabilty score= 38
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
39
41
43
45
47
49
51
53
55
57
59
FARMS NUMBERED FROM N=1 TO N=60

Appendix 5 Correlation between economic and environmental sustainability in vegetable production

Economical / Environmental	Productivity	Profitability	Efficiency	independence	Resilience	Transferability
Diversity	-0.347**	0.164	-0.363**	0.050	0.076	-0.054
Organisation of space	0.018	-0.083	0.317*	0.027	-0.014	0.156
Nutrient management	0.479**	0.297*	0.112	-0.041	0.115	0.334**
Pest management	0.100	-0.128	-0.117	-0.276*	-0.119	-0.126
Farm machinery operations	0.287*	0.212	0.140	0.034	0.045	0.281*
External material disposability	0.218	0.064	0.060	0.149	0.164	-0.030
Soil conservation	0.026	-0.127	-0.096	0.189	0.072	0.100
Water management	0.395**	0.175	0.160	0.087	-0.062	0.128
Energy consumption	-0.408**	-0.049	0.046	0.086	-0.037	-0.195

Note: ***, ** and * indicates significance at 1%, 5% and 10% levels, respectively

Appendix 6 Correlation between indicators of economic sustainability scores in vegetable production

Economic indicators	Productivity	Profitability	Efficiency	independence	Resilience	Transferability
Productivity	1	0.219	0.290*	0.123	-0.018	0.149
Profitability	0.219	1	-.0391**	-0.331**	-0.044	-0.085
Efficiency	0.290*	-0.391**	1	-0.046	-0.056	0.286*
independence	0.123	-0.331**	-0.046	1	0.018	-0.025
Resilience	-0.018	-0.044	-0.056	0.018	1	0.067
Transferability	0.149	-0.085	0.286*	-0.025	0.067	1

Note: ***, ** and * indicates significance at 1%, 5% and 10% levels, respectively

Appendix 7 Correlation between environmental sustainability scores in vegetable production

Environmental Indicators	Diversity	Organisation of space	Nutrient management	Pest management	Farm machinery operations	External material disposal	Soil conservation	Water management	Energy consumption
Diversity	1	-0.122	-0.198	-0.362**	-0.140	-0.359**	0.027	0.089	0.427**
Organisation of space	-0.122	1	-0.027	-0.100	0.099	-0.006	-0.141	-0.032	0.046
Nutrient management	-0.198	-0.027	1	0.055	0.221	0.357**	0.057	0.128	-0.512**
Pest management	-0.362**	-0.100	0.055	1	-0.238	-0.152	0.021	-0.127	-0.593**
Farm machinery operations	-0.140	0.099	0.221	-0.238	1	0.276*	0.071	0.055	-0.106
External material disposability	-0.359**	-0.006	0.357**	-0.152	.276*	1	0.196	-0.221	-0.352**
Soil conservation	0.027	-0.141	0.057	0.021	0.071	0.196	1	-0.087	-0.240
Water management	0.089	-0.032	0.128	-0.127	0.055	-0.221	-0.087	1	-0.075
Energy consumption	0.427**	0.046	-0.512**	-0.593**	-0.106	-0.352**	-0.240	-0.075	1

Note: ***, ** and * indicates significance at 1%, 5% and 10% levels, respectivel