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# Interlinking dietary diversity, production diversity, and climate change: Non-separable farm household model approach

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**Abstract** The level of production diversity is an indirect measure of diet quality and nutritional security. But production decisions are impaired by changes in climate. This study provides an empirical application of the non-separable household model by linking the effect of exogenous variations in production decisions, via climate variability, on household dietary diversity. Climate-induced production shocks cause fluctuations in food supply and market prices and, thereby, decrease dietary diversity and nutritional security. To combat the effects of climate change on subsistence farm households and improve nutritional security, production diversity and farm income are equally important, and agricultural policy should aim to enhance both.

**Keywords** Production diversity, dietary diversity, non-separability, farm households, semi-arid tropics

**JEL codes** E23, E21, C33, Q121

In many empirical and theoretical studies of economic development, the farm household model plays a central role (Singh et al. 1986). The model integrates the production of goods consumed by a farm household into a standard utility maximization framework, and it has been used to provide important insights into a broad array of economic questions (Chayanov 1966). This model has been used in many research studies like nutrition and labour market linkages (Strauss 1982); labour supply, determination of wages, and shocks in agricultural productivity (Kaur 2019); risk and investment in human capital (Jacoby and Emanuel 1997); resource allocation among family members (Rangel and Duncan 2015); technology adoption (Barnum and Squire 1979; Conley and Udry 2010); microcredit and financial markets (Kaboski and Townsend 2011); and the interlinkage of climate change and production and consumption decisions (Dillon et al. 2015).

We elaborate on the background linkages of climatic factors, production activities, and consumption decisions in the conceptual framework (Figure 1), which focus the farm household as a central decision-making unit. We improve and formalize our original conceptual framework (Khed et al. 2018) and we make some adjustments to fit the context of this study. We define three possible pathways through which farmers' decisions can be influenced; two are related to climatic factors and one is independent of climatic factors. Changes in climate parameters can affect farmers directly or indirectly. The direct effects are on production activities such as crop and livestock, while indirect effects focus are food consumption. These influence the decision-making and well-being of farm households positively and negatively.

The independent effect refers to general socioeconomic characteristics such as age, education, and other household characteristics. The present study hypothesizes that production diversity positively influences household dietary diversity and, subsequently, household food security. However, farmers' production decisions potentially determined

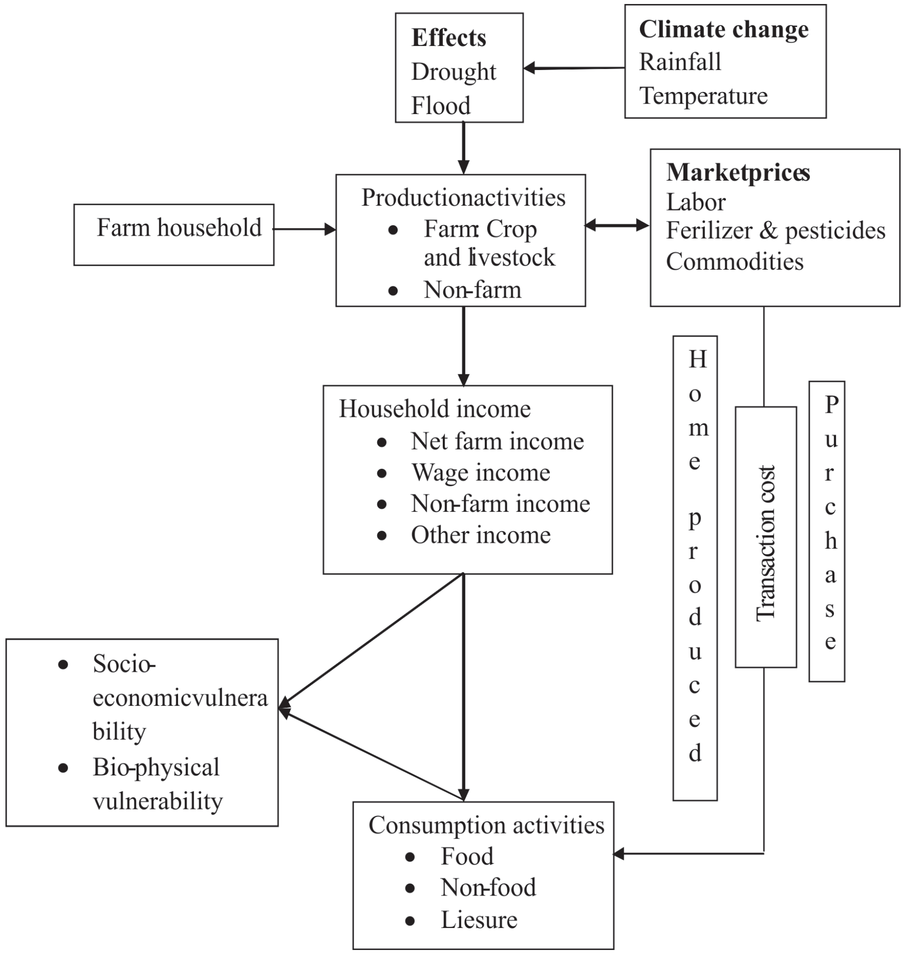


**Figure 1 Conceptual framework of farm households**

by climatic factors. Smallholder farmers, for instance, are more likely to grow food crops to ensure food self-sufficiency than grow cash crops and thus have low income elasticity in staple food expenses (Fafchamps 1992). Farm size is an important determinant of the quality of farm households' livelihoods—larger the farm, better the livelihood (Khed et al. 2018).

In India, the average farm size is 1.15 ha, and 85% of the farmers have landholdings of 2 hectares at most. They can produce diversified foods; therefore, they are almost self-reliant and less dependent on purchases. Farms may also be specializing in growing and selling commercial crops and, if necessary, buying most of its food needs (Nayak and Kumar 2019). The production decision is majorly determined by the distance between the farm and market (transaction cost). For a household at a remote location, the costs incurred in buying and selling goods and services, or transaction costs, are high, and the gap between selling and buying prices is large. This makes it follow the subsistence path. If transaction costs are low, then the household is more likely to specialize in the production of certain crops, ceteris paribus.

The agricultural production decisions and livelihood of farmers and other stakeholders are heavily influenced also by the increasing frequency of extreme climatic events such as droughts, floods, and heatwaves (Cheteni et al. 2020; Das and Ghosh 2019; Birthal et al. 2014), which reduce the farm-dependent consumers' choice of diversified food items. A general hypothesis derived from the multiple functions of farm households is that their production and consumption decisions are interrelated and influenced by climatic factors (Barnum and Squire 1979; Dillon et al. 2015; Singh et al. 1986). Here, we focus on the effect of exogenous variation in production decisions via climate variability on household dietary diversity.

To make this framework applicable to empirical analysis, we have to specify indicators to measure the effects of climate variability, agricultural production, and diet diversity. Some empirical studies find that production diversity remedies food insecurity (Dillon et al.;. 2015; Kumara et al. 2016; Sekabira and Shamim 2020) and others hold that markets constitute the solution (Sibhatu et al. 2015). The evidence is mixed and it may vary by region or country. Further, the limited studies observed the simultaneity of production and household consumption using climatic factors as an external variable. This study contributes to the literature by examining the link between agricultural production and dietary diversity using the data from India's semi-arid tropical regions on household consumption, agricultural production, and geospatial variables like rainfall and temperature.

## Data and empirical strategy

The study is based primarily on secondary data collected from the 'Village Dynamics in South Asia (VDSA)' by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The project represents larger production regions within India's semi-arid tropics (SAT). We used the data for the 2009–14 period from 18 villages of 5 states: Andhra Pradesh (AP), Gujarat (GJ), Karnataka (KN), Maharashtra (MH), and Madhya Pradesh (MP)[1].

The data was collected continually from farm households. During data collection, the resident investigators re-interviewed the participating farm households several times per year to capture their dynamics—income, expenditure, consumption, investment, socio-demographic, farming practices, and climate variables. In each village every person in the sample households was interviewed at 15-day intervals using a standard questionnaire[2] (the detailed methodology is explained in Walker and Ryan (1990)). A sample of 30 cultivators and 10 landless labourer households under 3 different categories (small, medium, and large) was drawn in each village, and it formed the panel data for 664 farm households.

The average operational landholding of small farmers is 1.13 ha followed by medium (2.25 ha) and large (5.11 ha); the overall average across SAT villages is 2.53 ha. Households are separated further into degree day and rainfall deviation quartiles, where deviations from the historical mean of the climate variable are calculated to understand climate shocks. A positive shock indicates above-average degree days or rainfall while a negative shock indicates below-average.

## Measurement of farm production diversity and dietary diversity

Farm production diversity is measured using two indices: the biodiversity index and the aggregated food production score. The biodiversity index is a simple count of all crops and livestock produced on the farm (Jones et al. 2014; Sibhatu et al. 2015; Kavitha et al. 2016). The aggregated food production score measures the sum of food groups produced on the farm. To construct the food production score, food crops were separated into 5 groups that correspond to 5 out of 12 groups that comprise the dietary diversity measure; non-food crops were excluded.

Dietary diversity is measured using two indices, similar to those used to measure production diversity, such as food item count, food group count. However, Jones et al. (2014) and Sibhatu et al. (2015) state that various approaches can be used to measure dietary diversity and emphasized to compare available quantities of particular foods, diets, and societal food behaviour. Therefore, many researchers use the food variety score—a simple count of food items consumed by households—and the dietary diversity score, an aggregated count of food groups consumed by the households (Cheteni et al. 2020; Sibhatu et al. 2015; Kumara et al. 2016).

Hence, the food variety score and dietary diversity score capture the access of households to different food products, their ability to afford these, and their food behaviour. The food groups are defined according to the guidelines of the Food and Agriculture Organization (FAO). The index ranges from 0 and 1, where 1 indicates positive effect on consumption of that particular item and 0 otherwise.

### Non-separable farm household model

The non-separable farm household model is used to examine the connections between diversity of farm

[1] The study villages map is available at ICRISAT website (*http://vdsa.icrisat.ac.in/*).

[2] The questionnaire and data collection methods and the data are available at vdsa.icrisat.ac.in/VDSA-database.htm.

production, dietary diversity, and climate variability. The model explains the causal effect of diversity in production on dietary diversity. In the separable model, production and consumption are treated as two different sets. The definition of the interconnection between output (income) and consumption (nutrition) may be distorted by the inability to separate the causal path of the interlinkage, which correlates directly to production and consumption; that is, higher production (income) may have improved consumption (nutrition) and, similarly, households with better consumption (nutrition) may also have higher productivity and higher income.

By modeling this causal relationship using a non-separable household model and using exogenous variation in degree days, rainfall, and agricultural capital as an instrument, the causal direction of the production–dietary diversity relationship is more clearly identified (Dillon et al. 2015). Rainfall and degree day shocks are deviations from historical mean values (the historical mean and standard deviation of climate variables for the 1990–2014 period is given in Table A1 in the Appendix). A degree day is a cumulative measure of optimal temperatures for plant growth. A positive shock indicates above-average degree days or rainfall, while a negative shock indicates below-average. Hatfield et al. (2008) studied the impact of climate change on agriculture, land, water, and biodiversity using degree days as a climatic variable and found increase in temperature having a negative impact on crop yields and agricultural income.

## Empirical model

In a non-separable household model, production and consumption decisions are jointly determined (Bardhan and Udry 1999; Strauss 1982). The detection of the direction of causality is probably confounded by a cross-sectional correlation. In this empirical strategy, a reduced form of regression equations of climate variables on diet would also be mis-specified due to omitted production variables (Dillon et al. 2015).

These challenges were addressed by developing a dynamic non-separable household model that used planting and harvest season data to improve the identification of production-consumption elasticity estimates. This strategy distinguishes between the timing of seasonal production decisions to understand the effect of planting period production decisions on post-harvest dietary diversity within a full agricultural year. We adopted the technique developed by Dillon et al. (2015) for panel data. In the formulation of the dynamic household model, households maximize expected utility given the production function ($Y_t$), time endowment ($E^t$), and intertemporal budget constraint ($Q_t$). The household's problem is to choose produced agricultural goods ($x_{at}$), agricultural inputs ($V_t$) and leisure ($l_t$) to maximize given utility ($\mu_t$) and unobserved household characteristics ($\varepsilon_t$) such that:

$$U_t = \max E\left[\sum_{t=0}^{\infty} \beta^t\, u(x_{at}x_{mt}, l_t;\ \mu_t, \varepsilon_t)\right] \quad \ldots(1)$$

subject to the constraints:

$$Q_t = Q_t\,(L_t, V_t, A_t;\ \theta) \quad \ldots(2)$$

$$E^L = l_t + L^F_t + L^0_t \quad \ldots(3)$$

$$W_{t+1} = (1 + r_{t+1})\,[W_t + w_t\,(E^L - l_t) + \pi - p_{at}x_{at} - p_{mt}x_{mt}] \quad \ldots(4)$$

where $\pi_t = p_{at}Q_t\,(L_t, V_t, A_t;\ \theta) - w_tL_t - p_{vt}V_t - p_AA_t$ is the profit function over season t. The production function presented in Eq. (2) depends on the vectors of farm labour ($L_t$), variable inputs ($V_t$), fixed assets ($A_t$) such as land and capital, and seasonal climate variability (θ). The households time endowment (Eq. 3) is divided between leisure, on-farm ($L^F_t$) and off-farm labour ($L^0_t$). A standard dynamic household budget constraint is represented in Eq. (4).

In a separable household model, the demand for consumption of good c in period t is:

$$X_{ct} = x_{ct}\,(p_{mv}, p_{av}, w_v, r_{t+1}, \pi_t\,(p_{vV}, p_{aV}, p_V, p_{At};\ \theta), \gamma_V, \lambda_V;\ \mu_t, \varepsilon_t) \quad \ldots(5)$$

where good c consumption depends on market ($p_{mv}$) and agricultural prices ($p_{av}$), the price of variable inputs ($p_v$) such as agricultural labour, fertilizer, pesticides or herbicide, interest rates ($r_{t+1}$), farm profits ($\pi_t$) conditional on climate variability ($\theta$), exogenous income ($\gamma_V$) and future prices via the marginal utility of wealth ($\lambda_V$).

Consumption also depends on observed (size and composition) and unobservable household characteristics (food preferences). Here, the problem can be disaggregated into a recursive two-period problem where household first maximize profits and then choose consumption levels if we assume separability (Bardhan and Udry 1999; Singh et al. 1986).

In non-separable formulation, production factors such as input prices influence the households consumption choices such that

$$X_{ct} = x_{ct}\,(p_{mv}, p_{av}, w_v, r_{t+1}, \pi_t\,(p_{vV}, p_{aV}, p_V, p_{At}; \theta), p_{vV}, p_{aV}, p_v p_A, \gamma_V, \lambda_V; \mu_t, \varepsilon_t) \quad \ldots(6)$$

Input prices affect household consumption when markets are imperfect. We cannot assume that only income affects household consumption demand. Therefore, the consumption demand equation includes not only variables that affect household income but also those that affect production decisions. The identification strategy to disentangle the joint production and consumption decision by the household is to model the production–climate variability relationship as a first-stage regression—controlling for other production variables, including labour availability and agricultural capital—while also controlling for prices and including household level fixed effects. The household fixed effects control for potentially omitted variables that are unobserved in our data set—including the interest rate and price expectations which, we assume, are similar across rural areas within states.

In the second stage, the relationship between production-related variables (agricultural revenue and production diversity) and dietary diversity was examined. The demand for a consumption good is generalizable to a dietary diversity indicator, or calories consumed by the food group after converting food quantities into calories—more precisely, the first-stage relationship between production ($Y_{hvs}$) is determined by input prices ($p_v$), the value of agricultural capital ($p_A$), climate variability ($\theta_{hs}$) and household characteristics including household size and composition (X):

$$\ln Y_{hvs} = \beta^{pv} p_v + \beta^{A} p_A + \beta^{\theta}\theta_{hvs} + \beta^{\theta} X_{hvs} + \lambda_s + \varepsilon_{hvs} \quad \ldots(7)$$

where,

$Y_{hvs}$ = agricultural return/production diversity

$p_v$ = input prices in the village

$p_a$ = value of agricultural capital

$\theta_{hs}$ = climate variability

$\lambda_s$ = village fixed effects

$\varepsilon_{hvs}$ = error term

Here, the relationship between production and climate variability includes the specification of $Y_{hvs}$ as either crop group count score in the first set of regressions or agricultural revenue in the second set of regressions. Farm capital is a quasi-fixed stock over the agricultural season considered in the analysis. The motivation for the inclusion of agricultural capital is clear from the agricultural production function: agricultural capital and input prices directly affect the production and hence agricultural revenue. Household fixed effects (λ) are also included in this regression to control for agricultural market integration that may affect either access to inputs or marketing opportunities for farmers.

The second-stage equation establishes the relationship between production and dietary diversity at the household level, and it is given by:

$$\ln N_{hvs} = \beta^{Y} \ln Y_{hvs} + \beta^{pm} p_m + \beta^{pv} p_v + \beta^{X} X_{vhs} + \lambda s + \varepsilon_{hvs} \quad \ldots(8)$$

where $N_{hvs}$ is dietary diversity for household 'h' in village 'v' in state 's'. Dietary diversity is determined by agricultural production Y, market price ($p_m$) during the post-harvest period, variable input prices ($p_v$), and household characteristics X including household composition which may affect household consumption. Here, Y is endogenously determined instruments with local climate variables and agricultural capital that are correlated with production variables but uncorrelated with dietary diversity. The plausibility of the excludability condition depends on the spatial intensity of climate shocks and market integration.

While climate shocks could have an effect on dietary diversity via price variation, the econometric specification includes market prices in the second stage. Further, the variability in the local climate causes a reduction in yield for local farmers, but these climate-induced yield reduction have less of an effect on equilibrium prices. Hence, a pathway through which climate variation affects dietary diversity is the number of crops available for the household's own consumption or, in our second specification, through the agricultural income generated from production, but price changes induced by the variability in the local climate do not affect dietary diversity.

**Testing the exclusion restriction**

The validity of the exclusion restriction potentially invalidates the identification of the effect of production variables on consumption outcomes. The primary concern is that climate variation may be correlated with dietary diversity. This would be the case if climate variation produced general equilibrium price changes that, in turn, affect consumption through market prices independently of their effect on production.

To test the mechanism and to find the evidence that the exclusion restriction is indeed invalid would be to estimate the effect of climate directly on market-level prices. We can directly estimate any potential general equilibrium effects of variations in the climate on market prices through a deviation from the historical average of either degree days or rainfall. To test a potential mechanism that would violate the exclusion restriction, we estimate the climate–price specification, the unit of analysis that most closely correlates to local markets. If strong correlations exist between climate shocks and market prices, the exclusion restriction would be violated.

## Results and discussion

Farm household production decisions are determined by prices of inputs as well as by output and climate factors. To factor out the price from the climatic effect, it is imperative to examine the price of inputs and outputs during the study period. Hence, the average prices of agricultural inputs and composite prices for the food groups are computed and presented in Table 1.

**Table 1 Input cost and output price (INR)**

| Inputs/Outputs | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | Average | CGAR |
|---|---|---|---|---|---|---|---|---|
| **Inputs** | | | | | | | | |
| Agricultural wages for male | 116.74 | 144.55 | 174.26 | 191.06 | 212.04 | 224.99 | 182.21 | 14.56*** |
| | (47.90) | (52.14) | (77.54) | (62.05) | (64.28) | (64.28) | (72.08) | |
| Agricultural wages for female | 70.20 | 99.33 | 119.33 | 123.93 | 140.07 | 143.03 | 119.35 | 15.55*** |
| | (32.32) | (46.94) | (63.37) | (56.79) | (48.94) | (48.29) | (56.09) | |
| Fertilizer price/kg | 8.33 | 13.25 | 15.89 | 15.47 | 17.58 | 18.95 | 15.33 | 11.26*** |
| | (2.29) | (43.32) | (34.69) | (8.83) | (29.80) | (54.76) | (35.57) | |
| Pesticide price/kg | 440.14 | 858.44 | 1288.73 | 97.00 | 1358.88 | 1747.09 | 1248.95 | 16.60*** |
| | (553.29) | (1493.21) | (2979.68) | (25.76) | (2303.01) | (4115.26) | (2715.60) | |
| **Outputs** | | | | | | | | |
| Market price of cereals/kg | 17.49 | 16.98 | 18.45 | 22.28 | 23.69 | 25.17 | 20.90 | 7.83*** |
| | (9.71) | (8.46) | (8.46) | (10.47) | (11.54) | (12.70) | (10.87) | |
| Market price of pulses/kg | 37.55 | 81.64 | 46.75 | 53.41 | 51.44 | 58.15 | 56.81 | 9.14*** |
| | (15.39) | (430.36) | (17.40) | (16.47) | (16.78) | (21.17) | (185.01) | |
| Market price of oilseeds/kg | 30.38 | 38.07 | 72.22 | 72.28 | 47.67 | 50.11 | 53.10 | 12.07*** |
| | (12.47) | (18.64) | (130.45) | (111.52) | (18.82) | (21.35) | (76.52) | |
| Market price of milk and milk | 39.29 | 24.01 | 26.56 | 30.33 | 31.80 | 32.68 | 30.41 | 9.78*** |
| products/litre | (61.75) | (16.14) | (6.94) | (24.32) | (6.75) | (7.65) | (26.25) | |
| Market price/egg | 3.29 | 3.52 | 3.68 | 4.19 | 4.68 | 4.62 | 4.05 | 7.89*** |
| | (1.20) | (0.73) | (0.73) | (0.64) | (0.72) | (0.63) | (0.93) | |
| Market price of meat/kg | 150.15 | 166.40 | 191.15 | 225.63 | 245.96 | 256.42 | 209.39 | 14.66*** |
| | (49.02) | (61.11) | (75.45) | (92.50) | (92.52) | (104.67) | (91.54) | |
| Market price of fish and | 95.34 | 101.57 | 103.97 | 116.71 | 124.77 | 126.42 | 112.24 | 7.55*** |
| seafood/kg | (38.46) | (35.32) | (36.69) | (46.96) | (43.75) | (40.08) | (42.00) | |
| Market price of sugar and | 34.64 | 31.35 | 32.57 | 37.19 | 36.28 | 35.25 | 34.60 | 1.65** |
| sweets/kg | (4.78) | (5.00) | (4.07) | (4.58) | (5.12) | (5.85) | (5.38) | |

*Note:* Figures in parentheses indicate the standard deviation *** and ** Significant at 1% and 5% level, respectively.

During the study period, the prices of all the inputs and food items were increased significantly. The average daily male agricultural wage rate was increased from INR 116 per day in 2009 to INR 224 per day in 2014 at a compound annual growth rate (CAGR) of 14.56%. Further, the wage rate of female labour was increased at a CAGR of 15.55%, and the current wage rate was around INR 143 per day. Similarly, the fertilizer prices were increased at a CAGR of 11.26% and pesticide prices were increased at a CAGR of 16.60%. Fertilizers are subsidized; therefore, their average price (INR 15.33 per kg) was cheaper than of pesticides (INR 1,248.95 per kg).

Food prices follow a predictable pattern. Farm households abound in villages; therefore, the supply of cereals and milk and milk products is abundant, and these are relatively cheap. Other high-value food items (fruits, vegetables, meat, and eggs) were more expensive. The CAGR of meat prices was highest (14.66%) and least for sugar and sweets (1.65%). Food prices are influenced by factors that affect the supply or demand of a product, with variations depending on the nature of the product.

**Production, dietary diversity, and climatic shocks**

This section examines the descriptive linkages between production, climate, and household dietary diversity. The sample farmers are categorized based on degree days and rainfall deviations quartiles, where the deviations from the historical mean of the climate variables are as explained in the methodology. The farmers in the first quartile experienced larger negative deviation (for example, below-average rainfall and fewer degree days) while those in the fourth experienced larger positive deviations (for example, higher rainfall and more degree days). An increase in the number of degree days negatively affect crop yield and agricultural return for a variety of crops (Dillon et al. 2015).

**Agricultural production and climatic shocks**

The descriptive statistics of agricultural production across the farms grouped under degree days and rainfall shock quartiles are given in Table 2. For both degree days and rainfall shock, an inverted-U-shape relationship was observed: the agricultural return was highest when the deviation from the average weather was small and smallest when the deviation was largely positive or negative. Negative rainfall shocks and positive degree day shocks have a positive effect on the agricultural return. Further, there was a strong relationship between degree day and rainfall variability and the variety of crops harvested by farmers that experienced above-mean temperature (degree days) and below- mean rainfall.

The relationship of crop groups with the number of food groups harvested by farmers also followed the inverted-U shape. However, the number of all crops harvested exhibits a weak positive relationship with degree day shocks and rainfall. This may be because many semi-arid crops are tolerant to drought and heat. Overall, the descriptive statistics expose the linkage between agricultural production and climatic shocks. The findings are in line with the results of Dillon et al. (2015), which examine the harvest value and production diversity across different quartiles of climate shocks.

**Household dietary diversity and climatic shocks**

The relationship between dietary diversity and food group consumption is explored in Table 3. The

**Table 2 Production diversity and climate change**

| Production | Degree day shock quartile | | | | Rainfall shock quartile | | | | Overall |
|---|---|---|---|---|---|---|---|---|---|
| | – Shock | | + Shock | | – Shock | | + Shock | | |
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | |
| Total harvest value | | | | | | | | | |
| Harvest value (INR) | 144,000 | 146,000 | 150,000 | 139,000 | 148,000 | 174,000 | 136,000 | 125,000 | 145,000 |
| Number of crops and crop groups harvested by households | | | | | | | | | |
| Crop group harvested | 2.70 | 2.78 | 2.88 | 2.73 | 2.66 | 2.89 | 2.79 | 2.76 | 2.78 |
| Number of food group harvested | 2.57 | 2.58 | 2.75 | 2.54 | 2.57 | 2.60 | 2.68 | 2.59 | 2.61 |
| Number of crops harvested | 4.27 | 4.25 | 4.48 | 4.22 | 4.39 | 3.91 | 4.39 | 4.10 | 4.22 |

**Table 3 Dietary diversity and climate shocks**

| Dietary diversity | Degree day shock quartile | | | | Rainfall shock quartile | | | | Overall |
|---|---|---|---|---|---|---|---|---|---|
| | – Shock | | + Shock | | – Shock | | + Shock | | |
| | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | |
| Dietary diversity (Food group count) | 8.59 | 8.45 | 8.62 | 8.78 | 8.40 | 8.87 | 8.61 | 8.60 | 8.62 |
| Dietary diversity (Number of food items) | 20.60 | 23.78 | 28.33 | 25.52 | 25.25 | 29.53 | 22.80 | 20.64 | 25.37 |
| %age of food groups consumption from own production | | | | | | | | | |
| Cereals | 36.40 | 44.13 | 44.28 | 41.23 | 49.87 | 33.34 | 39.19 | 43.03 | 41.22 |
| Pulses | 33.64 | 24.51 | 46.41 | 30.63 | 37.66 | 26.24 | 38.50 | 28.97 | 33.71 |
| Oilseeds | 0.48 | 0.92 | 0.69 | 1.00 | 1.62 | 0.11 | 0.79 | 0.53 | 0.76 |
| Milk and milk products | 50.66 | 60.44 | 44.97 | 42.88 | 56.38 | 42.69 | 49.17 | 49.21 | 49.75 |
| Fruits | 5.21 | 4.13 | 6.52 | 5.44 | 5.86 | 5.65 | 6.89 | 6.09 | 5.48 |
| Vegetables | 7.23 | 3.23 | 9.15 | 6.33 | 7.83 | 5.77 | 6.11 | 5.97 | 6.47 |
| Eggs (Number) | 2.92 | 3.03 | 2.12 | 2.89 | 2.06 | 3.32 | 1.96 | 2.68 | 2..82 |
| Meat | 2.72 | 3.16 | 1.69 | 4.62 | 1.09 | 3.21 | 2.06 | 2.43 | 6.54 |

estimates suggest that 'weather' variables are correlated with household dietary diversity.

The household dietary diversity of the 'number of food groups consumed' and degree days had a U-shaped response, implying that an increase in the temperature beyond the threshold negatively affects the number of food items consumed. The household dietary diversity of 'food items consumed' and degree days had an inverted-U-shaped response, implying that food group consumption is positively influenced.

Under rainfall shocks, however, the household dietary diversity of food groups and different food items consumed had an inverted-U-shaped relationship. That indicates that variations in climatic variables up to the threshold positively affect household dietary diversity; beyond the threshold, however, these variations negatively affect the household consumption of different food items or groups.

The percentage of food group consumption from own-farm production is presented in the second part of Table 3. Some drought- and heat-tolerant food groups show a positive relationship with climatic shocks; the remaining food groups show negative as well as mixed responses .

**Relationship between dietary diversity, agricultural return, and operational landholding**

The production and household dietary diversity estimates are presented in Table 4. The annual agricultural return ranged from INR 15,720 in the first

**Table 4 Dietary diversity, agricultural return quartiles, and land class**

| | Agricultural return quartiles | | | | Land class | | | Overall |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | |
| Agricultural return (' '000) | 15.72 | 51.10 | 109.69 | 402.96 | 71.38 | 121.20 | 271.10 | 144.87 |
| PDD (Crop group count) | 1.81 | 2.11 | 2.35 | 2.88 | 2.03 | 2.35 | 2.58 | 2.29 |
| PD (Food crop group count) | 1.75 | 2.07 | 2.26 | 2.66 | 1.56 | 2.04 | 2.37 | 2.18 |
| Dietary diversity (Food group count) | 8.08 | 8.07 | 8.27 | 8.49 | 8.26 | 8.22 | 8.21 | 8.23 |
| Dietary diversity (Food item count) | 20.74 | 21.33 | 23.02 | 24.30 | 22.44 | 22.11 | 22.10 | 22.25 |
| Consumed 3 or fewer food groups (%) | 0.00 | 0.70 | 0.00 | 0.52 | 0.35 | 0.50 | 1.14 | 0.60 |
| Consumed 4 to 6 food groups (%) | 0.00 | 0.70 | 0.00 | 0.00 | 0.35 | 0.00 | 0.57 | 0.30 |
| Consumed 7 to 9 food groups (%) | 98.94 | 98.59 | 98.10 | 96.91 | 98.95 | 97.52 | 96.02 | 97.74 |
| Consumed 10 or more food groups (%) | 1.06 | 0.00 | 1.90 | 2.58 | 0.35 | 1.98 | 2.27 | 1.36 |

quartile to INR 402,960 in the last (4th) quartile. The operational landholding size and agricultural return have a positive relationship. All crop groups and food crop groups had a positive relationship with agricultural return and landholding. It indicates that large operational landholdings helps to grow diversified crops and realize higher agricultural returns.

Household dietary diversity showed a positive relationship with agricultural returns. Curiously, the dietary diversity of small farmers was higher than of other landholding categories. This may be because sources other than agriculture provide small farmers a stable income and they consume primarily out of their production and also enjoy government benefits. More than 95% of farmers in all the climate quartiles and land classes.consumed 7-–9 food groups.

**Relationship between agricultural returns and dietary diversity**

In the first stage of the household panel regression (Table 5), we have seen the relationship between agricultural returns and farm household dietary

**Table 5 Agricultural return and dietary diversity**

| Variables | Panel fixed effect model | IV: I stage | IV: II stage |
|---|---|---|---|
| Agricultural return | | | |
| Log of agricultural return | 0.08*** | | 1.03*** |
| | (0.02) | | (0.23) |
| Instrumental variables | | | |
| Deviation from mean degrees days | | –0.01*** | |
| | | (0.004) | |
| Deviation from mean rainfall | | 0.06** | |
| | | (0.03) | |
| Interaction of rainfall and degree days | | –0.00006** | |
| | | (0.06) | |
| Log value of agricultural capital | | 0.26*** | |
| | | (0.04) | |
| Local input prices | | | |
| Log male adult agricultural wage | –0.86*** | –0.22* | –0.4*** |
| | (0.12) | (0.12) | (0.1563) |
| Log fertilizer price | –0.08*** | –0.08*** | –0.04** |
| | (0.01) | (0.01) | (0.02) |
| Log food commodity price | –0.03 | –0.08 | –0.12* |
| | (0.05) | (0.06) | (0.06) |
| Household characteristics | | | |
| Age | 0.03*** | 0.01 | 0.02*** |
| | (0.01) | (0.01) | (0.01) |
| Education | 0.08** | 0.002 | 0.0142 |
| | (0.04) | (0.03) | (0.036) |
| Family size | 0.02 | 0.01 | –0.06** |
| | (0.02) | (0.02) | (0.03) |
| Occupation | 0.20*** | 0.09 | –0.0526 |
| | (0.08) | (0.07) | (0.0928) |
| Gender | 0.30 | 0.32 | –0.31 |
| | (0.32) | (0.23) | (0.29) |
| Constant | 0.71** | 3.71*** | –6.90*** |
| | (0.33) | (0.56) | (1.52) |
| Durbin-Wu-Hausman $\chi^2$ | | 11.08** | |
| F-statistic | 10.31*** | 13.2*** | 10.85*** |
| Sargan and Basmann over-identification $\chi^2$ | | 4.6* | |

*Note:* Figures in parentheses indicate the standard deviation

***, ** and * – Significant at 1%, 5%, and 10% level, respectively diversity. The first column of Table 5 shows the results of a panel regression fixed effect model, which is included for comparison, and which shows a positive and significant correlation between dietary diversity and agricultural return. Further, input costs—like wages for male agricultural workers and fertilizer costs—had a negative and significant ($P<0.01$) relation with dietary diversity. The synergistic effect of fertilizer costs and wages on food commodity prices negatively affect dietary diversity. The household characteristics—like age, education, and occupation—were also positively related to dietary diversity.

The second column shows the first-stage results in establishing the relationship between the instrumental variables (climate variability and quasi-fixed agricultural capital) and production. The results from the first-stage estimation suggest that a higher number of above-average degree days in a season, and lower-than-average rainfall, is associated with lower agricultural returns—as expected. The first-stage results also suggest that a higher number of above-average rainfall days is positively and significantly ($P<0.01$) associated with returns, whereas the degree days and interaction of rainfall and degree days are found to be negatively and significantly ($P<0.05$) associated with the returns. The first-stage results also provide some evidence that agricultural capital is relevant to explaining the production. The value of agricultural capital is positively associated with agricultural return and dietary diversity.

The third column shows the main results from the second stage of the instrumental variable panel data fixed effect model estimation. Agricultural returns have a positive and statistically significant impact ($P<0.01$) on dietary diversity. The set of instrumental variables was strongly correlated with the endogenous variable reflected by the F-statistics ($P<0.01$). The specification also passes two benchmark tests: the Durbin-Wu-Hausman test for endogeneity and the Sargan and Bassmann test for over-identification. The estimates suggest that a 1%-increase in agricultural return will increase dietary diversity by 1.03%.

The results also indicate that input prices have a negative and significant effect on household dietary diversity and the household head's age has a positive effect. Family size has a negative and significant impact: smaller the family size, greater the dietary diversity. Male-headed households are less likely than female-headed households to have a diversified diet.

**Relationship between production diversity and dietary diversity**

Table 6 presents the panel regression results of production diversity on dietary diversity. These have a positive and significant ($P<0.1$) relationship, as observed in the first stage of the household panel regression: a 1-unit increase in product diversity will increase dietary diversity by 0.03 units. Further, male agricultural labour wages and fertilizer prices have a negative and significant ($P<0.01$) relationship with production diversity. If commodity prices have a negative sign, a rise in the price would directly reduce consumption and, thereby, household dietary diversity.

The second column of Table 6 shows the first-stage results in establishing the relationship between the instrumental variables (climate variability and quasi-fixed agricultural capital) and production diversity. The results suggest that production diversity would decrease if the number of degree days in a season is higher than the average or if the rainfall is lower than the average. Higher-than-average rainfall is positively and significantly ($P<0.05$) associated with high production diversity. The instrumental variable—the value of agricultural capital—was positively associated with production diversity and dietary diversity. It shows that a 1%-increase in agricultural capital increases dietary diversity 0.26% through production diversity. Further, wages and output prices had a negative impact on diet diversification.

The third column of Table 6 shows the results from the second stage of the panel data fixed effects model with instrumental variable estimation. As expected, the production diversity had a positive and significant ($P<0.01$) impact on dietary diversity: an increase of 1 unit in production diversity increases dietary diversity by 1.76 units. The significant F-statistics indicates that the set of instrumental variables included in the model were strongly correlated with the endogenous variable. The specification also passes two benchmark tests: the Durbin-Wu-Hausman test for endogeneity and the Sargan and Bassmann test for over-identification. Family size, occupation, and the household head's gender—but not age—had a negative and statistically significant impact on household dietary diversity.

**Table 6 Production diversity and dietary diversity**

| Variables | Panel fixed effect model | IV: I stage | IV: I stage |
|---|---|---|---|
| Production diversity | 0.03* | | 1.76*** |
| | (0.02) | | (0.37) |
| Instrumental variables | | | |
| Deviation from mean degrees days | | –0.01*** | |
| | | (0.004) | |
| Deviation from mean rainfall | | 0.06** | |
| | | (0.03) | |
| Interaction of rainfall and degree days | | –0.0001* | |
| | | (0.05) | |
| Log value of agricultural capital | | 0.26*** | |
| | | (0.04) | |
| Local input prices | | | |
| Log male adult agricultural wage | –0.54*** | –0.23* | –1.80*** |
| | (0.11) | (0.12) | (0.22) |
| Log fertilizer price/kg | –0.08*** | –0.08*** | –0.01 |
| | (0.01) | (0.01) | (0.02) |
| Log food commodity price/kg | –0.14*** | –0.08* | –0.31*** |
| | (0.06) | (0.06) | (0.06) |
| Household characteristics | | | |
| Age | 0.01 | 0.01 | 0.03*** |
| | (0.01) | (0.01) | (0.03) |
| Education | 0.01 | 0.002 | 0.02 |
| | (0.03) | (0.03) | (0.01) |
| Family size | 0.01 | 0.01 | –0.07** |
| | (0.02) | (0.02) | (0.02) |
| Occupation | 0.09 | 0.09 | –0.30** |
| | (0.08) | (0.07) | (0.06) |
| Gender | 0.26 | 0.32 | –0.54* |
| | (0.23) | (0.23) | (0.23) |
| Constant | 5.59*** | 3.71*** | –7.69*** |
| | (0.54) | (0.56) | (1.69) |
| Durbin-Wu-Hausman $\chi^2$ | | 4.12* | |
| F Statistic | 12.05*** | 11.4*** | 10.09*** |
| Sargan and Basmann over-identification $\chi^2$ | | 15.43** | |

*Note:* Figures in parenthesis indicates the standard deviation
***, ** and * – Significant at 1%, 5%, and 10% level, respectively

Smaller the family size, greater the dietary diversity. Households that practise agriculture as their primary occupation were less likely to have diversified diets than households that perform off-farm activities as a primary occupation. Agricultural income is not stable; farming households practised subsidiary occupation to make their income stable and improve dietary diversity. The dietary diversity was lower in male-headed households than in female-headed households. The results of the elasticity estimates of this study—production diversity and dietary diversity have a positive relationship—are supported by the findings of Dillon et al. (2015), for farming households in Nigeria, and of Sekabira and Shamim (2020), for farming households in Uganda.

**Table 7 Market prices and climate shocks**

| Output prices | Cereals | Pulses | Oilseeds | Milk and milk products | Eggs | Meat | Fish and seafood | Sugar and sweets |
|---|---|---|---|---|---|---|---|---|
| Mean degree day deviation | 0.03 | 1.45 | 0.51 | 0.47** | –0.77 | –0.01 | 0.27 | 0.02 |
| | (0.10) | (1.82) | (1.07) | (0.21) | (0.67) | (0.02) | (0.95) | (0.07) |
| Mean rainfall deviation | –0.26 | –14.79 | 6.86 | –0.70 | –0.06 | –0.21 | –12.76* | –0.36 |
| | (0.69) | (13.30) | (7.9125) | (1.54) | (5.26) | (0.12) | (7.60) | (0.53) |
| Interaction of rainfall and degree day deviation | –0.08 | –6.07* | 0.56 | –1.10*** | –0.37 | 0.06* | 3.88* | –0.21 |
| | (0.19) | (3.60) | (2.22) | (0.42) | (1.55) | (0.03) | (2.18) | (0.15) |
| Wage rates | 0.02*** | 0.28* | 0.28 | –0.002 | 0.18*** | –0.01 | –0.33*** | 0.01** |
| | (0.01) | (0.15) | (0.09) | (0.02) | (0.05) | (0.001) | (0.08) | (0.01) |
| Fertilizer price | 0.001** | –0.002 | 0.002 | 0.003*** | 0.01*** | –0.000004*** | 0.02*** | 0.0001 |
| | (0.001) | (0.009) | (0.01) | (0.001) | (0.003) | (0.00007) | (0.004) | (0.0004) |
| Constant | 15.87*** | 5.05*** | 0.58*** | 27.42*** | 167.64*** | 5.32*** | 155.85*** | 31.97*** |
| | (1.45) | (27.67) | (17.32) | (3.26) | (10.38) | (0.23) | (14.61) | (1.12) |
| Observation | 108 | 108 | 108 | 108 | 108 | 108 | 108 | 108 |
| R-square | 0.61 | 0.68 | 0.66 | 0.71 | 0.52 | 0.55 | 0.54 | 0.56 |

Note: Figures in parentheses indicates the standard deviation
***, ** and * – Significant at 1%, 5%, and 10% level, respectively

### Testing the exclusion restriction

If variations in climate parameters impact household dietary diversity through climate-induced price fluctuations, the instrument exclusion restriction is violated, and the instrumental variable results would be biased (Dillon et al. 2015). Therefore, we test the direct relationship between deviations in climate variables and local food commodity prices and present the results in Table 7.

If markets are relatively integrated, or production shocks are relatively minor, localized production shocks should not affect market prices. For most food groups, there is no significant relationship between climate deviations during the agricultural season and local prices.

Besides, most estimates of the effect are relatively small. Although for a few commodities climate deviations had a weak impact on prices, the exclusion restriction is not violated through the transmission of production shocks on commodity prices. Hence, the hypothesis of variation in climate has a significant effect on production and dietary diversity is failed to reject.

## Conclusions

The discussion about the interlinkages of agriculture and food consumption and agricultural pathways to increase nutrition is likely to occur through either effects on income or the increased consumption of own-produced food. For the impact of agricultural income and production diversity on dietary diversity, we used agricultural revenue and the variability in rainfall and in degree days. The variability of the climate is shown to have different effects on revenue versus variability in crop production. Historical variations in rainfall have statistically significant effects on agricultural revenue and production diversity. The low dietary diversity and elasticity of agricultural revenue demonstrate that farmers are growing more food crops to meet their food consumption requirements rather than for commercial purposes.

The study estimated the major effects of agricultural revenue and production diversity on dietary diversity: the effect of agricultural revenue on dietary diversity is smaller than that of the production diversity of farm households. The dietary diversity–production elasticities imply that an increase of 1% in agricultural revenue increases dietary diversity by 1.03% and that an increase of 1% in production diversity increases dietary diversity by 1.76%. We found that production significantly affects household dietary diversity, and that the influence of agriculture revenue on the diet is limited.

The intra-household role in production decisions and its effect on household consumption could be investigated in future work. Farmers do not change their decision to produce crops during or across the agricultural season, so future research could investigate when farmers choose to diversify into producing foods not normally consumed in local diets that meet the population's macronutrient or micronutrient needs. This would yield insights that would help policymakers design agricultural interventions that could be expected to have larger nutritional effects. Further, the policy intervention should target—beyond augmenting the income of agricultural households—at improving the nutrition of agricultural households to be broader than income.

## References


Bardhan, P, and C Udry. 1999. *Development Microeconomics*. Oxford University Press, New York. https://doi.org/10.1002/1099-1328(200010)12:7<1050::AID-JID676>3.0.CO;2-5

Barnum, H, and L Squire. 1979. An econometric application of the theory of the farm household. *Journal of Development Economics* 6: 79–102. https://doi.org/10.1016/0304-3878(79)90037-3

Birthal, P S, M D Tajuddin Khan, D S Negi, and Shaily Agarwal. 2014. Impact of climate change on yields of major food crops in India: Implications for food security. *Agricultural Economics Research Review* **27** (2): 145–155. doi: 10.5958/0974-0279.2014.00019.6

Chayanov, A K. 1966. *The Theory of the Peasant Economy*. Homewood, IL:Irwin. https://growthecon.com/assets/papers/alexander_chayanov_the_theory_of_peasant_economy.pdf

Cheteni, P, K Yohane, and M Gisele. 2020. Exploring food security and household dietary diversity in the Eastern Cape Province, South Africa. *Sustainability* 12, 1851. doi:10.3390/su12051851

Conley, T, and C Udry. 2010. Learning about a new technology: Pineapple in Ghana. *American Economic Review* 100: 35–69. doi:10.1257/aer.100.1.35

Das, U, and S Ghosh. 2019. Contrasting resilience of agriculture to climate change in coastal and noncoastal districts of Odisha. *Indian Journal of Agricultural Sciences* 89: 769–74. 10.1007/s00704-019-03061-x

Dillon, A, M Kevin, and O Gbemisola. 2015. Agricultural production, dietary diversity and climate variability. *Journal of Development Studies 51*. 10.1080/00220388.2015.1018902

Fafchamps, M. 1992. Cash crop production, food price volatility and rural market integration in the third world. *American Journal of Agricultural Economics* 74: 90–99. doi:10.2307/1242993

Hatfield, J, K Boote, P Fay, L Hahn, C Izaurralde, B A Kimball, and D Wolfe. 2008. *Agriculture*. In Backlund P, A Janetos, and D Schimel (eds.) *The effects of climate change on agriculture, land resources, water resources and biodiversity*. Washington, DC: US Climate Change Science Program and the Subcommittee on Global Change Research, pp.21–74. https://www.fs.fed.us/rm/pubs_other/rmrs_2008_backlund_p003.pdf

Jacoby, H, and S Emanuel. 1997. Risk financial markets and human capital in a developing country. *Review of Economic Studies* 64: 311–35. doi:10.2307/2971716

Jones, A D, A Shrinivas, and K R Bezner. 2014. Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data. *Food Policy* 46: 1–12. doi:10.1016/j.foodpol.2014.02.001

Kaboski, J P, and R M Townsend. 2011. A structural evaluation of a large scale quasi experimental microfinance initiative. *Econometrica* 79: 1357–1406. doi:10.3982/ECTA7079

Kaur, S. 2019. Nominal wage rigidity in village labor markets. *American Economic Review* 109: 3585–3616. doi: 10.1257/aer.20141625

Kavitha, K, P Soumitra, and R Padmaja. 2016. Understanding the linkages between crop diversity and household dietary diversity in the semi-arid regions of India. *Agricultural Economics Research Review* 29 (Conference Number): 129–137. doi: 10.5958/0974-0279.2016.00040.9

Khed, V, V Saravanakumar, and K B Umesh. 2018. Does farm size explain food consumption pattern? evidence from semi-arid regions of India. *Agricultural Economics Research Review* 31 (Conference Number): 47–55. doi:10.5958/0974-0279.2018.00021.6

Kumara, A, S Saroja, R K P Singh, and J Shiv. 2016. Agricultural diversity, dietary diversity and nutritional intake: an evidence on inter-linkages from village level studies in eastern India. *Agricultural Economics Research Review* 29 (Conference Number): 15–29. doi: 10.5958/0974-0279.2016.00030.6

Nayak, C, and C R Kumar. 2019. Crop diversification in Odisha: an analysis based on panel data. *Agricultural Economics Research Review* 32 (1). doi:10.22004/ag.econ.292204

Rangel, M, and T Duncan. 2015. Gender, production and consumption: allocative efficiency within farm households. International Food Policy Research Institute Discussion Paper 01195. http://ibread.org/bread/sites/default/files/0413conf/rangel.pdf

Sekabira, H, and N Shamim. 2020. Farm production diversity: is it important for dietary diversity?: panel data evidence from Uganda. *Sustainability* 12, 1028. doi:10.3390/su12031028

Shinoj, P, A Kumar, M C S Bantilan, and P K Joshi. 2015. Food consumption patterns and dietary diversity in eastern India: evidence from village level studies (VLS). *Food Security* 7: 1031–1042. DOI 10.1007/s12571-015-0493-2

Sibhatu, K T, V V Krishna, and Q Matin 2015 Production diversity and dietary diversity in smallholder farm households. *PNAS* 112: 10657–10662. http://www.pnas.org/cgi/doi/10.1073/pnas.1510982112

Singh, I, L Squire, and J Strauss. 1986. *Agricultural Household Models: Extensions, Applications and Policy*. Johns Hopkins University Press, Baltimore, MD. http://documents1.worldbank.org/curated/en/621291468739297175/pdf/multi-page.pdf

Strauss, J. 1982. Determinants of food consumption in rural Sierra Leone: application of the quadratic expenditure system to the consumption-leisure component of a household-firm model. *Journal of Development Economics* 11: 327–353. https://doi.org/10.1016/0304-3878(82)90010-4

Walker, T S, and J G Ryan. 1990. *Village and Household Economies in India's Semi-arid Tropics*. The Johns Hopkins University Press, Baltimore and London. http://oar.icrisat.org/485/1/RA_00151.pdf

## Appendix

**Table A1 Mean and standard deviation of climate variables, 1990–2014**

| Parameters | Village level |
|---|---|
| Annual temperature (°C) | 26.20 (1.20) |
| Maximum temperature (°C) | 32.86 (1.35) |
| Minimum temperature (°C) | 20.54 (1.75) |
| *Rabi* temperature (°C) | 23.59(1.39) |
| *Kharif* temperature (°C) | 25.88(1.60) |
| Annual rainfall (mm) | 842.36(281.04) |
| *Rabi* rainfall (mm) | 60.54(75.27) |
| *Kharif* rainfall (mm) | 614.54(246.02) |
| Rainfall days (number) | 67.45(17.12) |