Influence of High Temperatures on Milk Yields for Small-Holder Dairy Farmers in India.

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Abstract

The effect of temperature on agricultural yields is well documented in the literature, however effect of higher temperatures on milk yields is not so well known. In India, farming households with a few animals in their herd, produces most of the milk. This population is specially vulnerable to the effects of climate change. This study uses a nationally representative household survey of farmers to show that milk yields for these household dairy farmers is significantly reduced by exposure to temperatures above 25°c, with higher impact for temperatures above 35°c. With rising global temperatures, exposure to such high temperatures would increase, exacerbating the losses. For a 1°c rise in global temperature the loss would exceed 10% whereas for a 3°c rise the loss would cross 16% for the average farmer imposing a heavy burden in terms of lost income and nutrition.

Keywords: Milk yield, Climate change, Temperature, India .

JEL Classification Numbers: Q54, Q12, O53 .

1 Introduction

Anthropogenic climate change and the resultant rise in global temperatures, has been shown to adversely affect many important economic outcomes. For example, fall in GDP (Newell et al., 2021; Dell et al., 2012), incomes (Dell et al., 2009), human health and mortality (Deschenes, 2014; Deschênes and Greenstone, 2011), agriculture , child health and nutrition (Banerjee and Maharaj, 2020; Blom et al., 2022), worker productivity (Somanathan et al., 2021), to name just a few. It is also believed that these negative effects are likely to be more acutely felt in the sub-tropical regions which includes large parts of India Mendelsohn and Williams (2003). Out of all these outcomes, agricultural yield, is perhaps one of the best researched (Schlenker and Roberts, 2009; Auffhammer et al., 2012; Welch et al., 2010; Peng et al., 2004; Gupta et al., 2017). There is a rich literature that demonstrates this effect in detail using farm level productivity data matched to climate variables (Schlenker and Roberts, 2009; Schlenker and Lobell, 2010). However, most of this literature concentrates on the impact of exposure to high temperatures on yield of staple food crops like wheat, corn etc. A major part of agricultural produce stems from animal products, in particular milk and meat which would also be subjected to the ill-effects of climate change. While there is general agreement that animal productivity will be severely affected by high temperatures and increased precipitation resulting from climate change (Sirohi and Michaelowa, 2007; Thornton et al., 2009; Rojas-Downing et al., 2017), farm-level country-wide studies that can assess the economic impact on livelihoods and nutrition are absent.

In India milk production holds a special significance. Currently, India is the largest producer of milk in the world. In terms of monetary value milk production is worth more than the combined value of wheat and rice (the two most important food crops) [1]. The more interesting aspect of India's milk sector is that most of the production is carried out by small-holder farmers who own just 2-3 animals. Small-holder dairy farmers are a feature of most

[1] This information is sourced from Department of Animal Husbandry and Dairying, Ministry of Farming Animal Husbandry and Dairying, Government of India, as reported at the website of National Dairy Development Board here

less developed economies (Hemme and Otte, 2010). According to Rajendran and Mohanty (2004), in 1992, more than 67% of the very substantial livestock in India was held by such small farmers producing about 80% of the milk. These smaller-holder dairy farmers usually use low cost inputs and family labour to generate milk that may either be sold or consumed by members of the household. The households depend on their livestock for supplementing their diets as well as incomes (Herrero et al., 2013). Milk as a source of protein assumes special importance in many Indian households as a large proportion of them are vegetarians, for whom milk is the only source of animal protein. So any adverse effect on the productivity of these animals is likely to put pressure on a vulnerable part of the Indian society.

In India milk is produced mostly from cattle and water buffaloes. There is a large literature on the effect of heat on the physiology and performance of cattle. Most of these are either experimental studies or small scale studies done in a controlled environments (see Chen et al. (2023) for a meta analysis and Das et al. (2016) for a review of this literature for dairy cattle), some also use aggregate data at the state or country level (St-Pierre et al., 2003). Much of this research concentrates on the temperate regions and on cattle breeds more common in developed countries, however a parallel literature exists that looks at the same issue in the less-developed/sub-tropical region. For example, seeMrode et al. (2020) for a study based in sub-Saharan Africa. Good reviews of this literature exists for both cattle and buffaloes (Sirohi and Michaelowa, 2007; Thornton et al., 2009; Rojas-Downing et al., 2017; Choudhary and Sirohi, 2019, 2022), the latter are generally found to be slightly better adapted to hot climes. This research shows that milch animals like cattle and buffalo experience heat stress in tropical climate for temperatures above $25 - 37°$ leading to physiological symptoms that reduce food intake, yield, and reproduction. The temperature range at which animals experience such discomfort also depends on humidity. Given the relatively high average temperatures in most parts of India, one would expect quite extensive exposure of animals to temperatures beyond their thermoneutral range (this is the range of temperature where the animals can keep their body temperature stable). This literature also tells us that the impact of heat stress depends on farm management practices (Hill and Wall, 2015), and animals may be able to adapt to heat. As such I expect the reaction of animals to heat to be non-linear in nature and may be contingent on household characteristics of the owner.

This paper attempts to contribute to the literature on the impact of climate change on economic outcomes by looking at how milk yields obtained by small household dairy farmers are impacted by exposure to higher temperatures. For this I use data from a country-wide representative household level survey of rural farmers collected by the National Sample Survey Office of India. Under a couple of simple assumptions I can calculate milk yield obtained by the farmer from their livestock. With this I merge weather data by district and date of survey. I divide the range of temperature into four temperature bins and I construct a variable indicating the number of hours exposed to each of the bins in the last 30 days before the date of survey. I use this data to test if exposure to high temperatures have a bearing on milk yields obtained. I use different combinations of spatial and temporal fixed effects to control for regional and seasonal factors. Along with that I also include various household characteristics to control for the management and organisation practiced in the farmer household.

Results from this analysis indicate that for every extra hour exposed to temperatures above 35° milk yield for cattle and buffaloes goes down by 0.1% and 0.09% respectively compared to the base category of temperature below 15°. I also find significant negative impact for the average maximum/minimum temperature in the last 30 days, and exposure to higher range of average maximum/minimum temperature in 30 days before the date of survey. Implications of these results can be quite severe on the relatively poor rural agricultural households in India. I calculate that if I assume a uniform increase of temperature of 1° throughout the country, the resultant distribution of hours across different temperature bins would lead to a fall of more than half a litre in daily milk yields. In terms of milk proteins this a loss of close to 5 grams of protein per person per day which is substantial. If I convert the loss into monetary terms using average per unit value of milk, this amounts to between

740-900 Indian rupees lost per month per household. This is also a formidable loss for poor rural households. In addition, I estimate that the impact of the average levels of exposure above 35 on milk yield is likely to increase significantly as global temperatures go up. For a 1°c rise in global temperature the loss would exceed 10% whereas for a 3°c rise the loss would cross 16% for the average farmer imposing a heavy burden in terms of lost income and nutrition.

The rest of the paper is arranged as follows: Section 2 introduces the data sets used and how they are merged, this is followed by Section 3 which presents the main empirical results, Section 4 concludes.

2 Data

2.1 Milk Yield Data: NSS

I use the 77th round of the Farmers' Situation Assessment survey conducted by the National Sample Survey Office of India (NSS) in 2019. This is a cross-section of rural farming households, and is a country-wide representative survey. The survey collects information on various agricultural operations including the size, nature, and state of livestock held by these households. In addition I have information about total milk produced by the household in the last 30 days separately for cattle and buffaloes. Using the survey design of this survey I can estimate the total number of milch animals (cattle + buffalo) to be about 214 million. This turns out to be about 71% of total milch animals in the country as estimated in the 20th Livestock Census of India conducted in 2019[2]. Unfortunately, there is no direct question in the survey about yield. However, I can generate a good estimate of milk yield by dividing quantity of milk produced by the number of animals in-milk. While calculating yield I make the assumption that the number of animals in milk at the time of survey gives us a good estimate of the number of animals in milk at any point in time for the particular household.

[2] As reported in the annual report of the Department of Animal Husbandry and Dairying (DAHD) Ministry of Fisheries, Animal Husbandry and Dairying Government of India, for 2019-20, chapter 1 page 4

While this may not hold for each household, it should be true of the average household. The data of milk production, on the other hand, is collected with a 30 day recall period. I divide this by 30 to generate an estimate of the daily production. Summary statistics of the estimated milk yield along with other details collected from the NSS survey are presented in Table 1 and Table 2 respectively. I see that out of the total number of households surveyed, roughly 20% own cattle and 10% own buffaloes. Herd size for either animal is close to 2.5 out of which on an average 1 animal is in milk for buffaloes and 0.8 animals are in milk for cattle at any point. This indicates that buffaloes are probably more likely to be used for milk production which is also borne out by the gender ratio among buffaloes in India which is more skewed to the female side. These statistics paint a picture that is very close to a farmer's dairy operations as described in the literature. Milk yield is quite poor for both breeds with buffaloes doing slightly better with 3.22 liters/animal/day as opposed to 2.58 for cattle. Although these average yields are lower than those reported in the annual report of the Department of Animal Husbandry and Dairying, it is not surprising as our sample excludes large scale modern dairy operations that are likely to be better managed allowing them to achieve higher productivity.

We are also able to gather information about the households from the NSS survey. These have been reported in Table 2, separately for the full sample, cattle-owners, and buffalo-owners in columns 1, 2, and 3 respectively. It is noteworthy that there are significant differences between the sample of cattle-owners and the buffalo-owners. For example, using a simple t-test between these to samples it can be seen that buffalo-owners are more likely to be from the Scheduled Castes (SC), Other Backward Castes (OBC), rather than Scheduled Tribes (ST). Also, percapita monthly consumption expenditure is significantly higher for buffalo-owners. Lastly, I see that for buffalo-owners the household is significantly more likely to be deriving income primarily form livestock, and less likely to be deriving income primarily from casual agricultural labour. Taken together these statistics suggest that buffalo-owners are on an average economically and socially stronger.

2.2 Weather Variables: IMD

Daily gridded ($1^\circ \times 1^\circ$) resolution data on minimum, maximum temperature and rainfall over the period of the NSS survey were obtained from the Indian Meteorological Department (IMD). I create daily district-level data by constructing the area-weighted average temperature and rainfall of all the grid cells intersecting a 2011 district. Using this I create average maximum temperature, minimum temperature, and rainfall in the 30 days following the date of the NSS survey, for each date of survey, in each district. This is the main independent variable of interest in my first specification. I also construct variables to measure exposure to different temperature bands in the last 30 days. For this I divide the range of temperatures into 4 intervals starting from below 15 degrees, and then increasing in 10 degree intervals to 45 degrees. First I construct variables that counts the number of days in the past 30 (starting from the date of NSS survey) when daily maximum/minimum temperature happened to be in one of the intervals. In addition I follow Schlenker and Roberts (2009) to measure the total number of hours exposed to the four bins in the 30 days prior to the date of survey. For this I had to assume that temperatures move from the minimum to the maximum in a day according to a sine curve. Summary statistics of some of these variables are reported in Table 3. It is noteworthy that the minimum temperature is above $35^\circ c$ on very rare occasions, however, for the sake of consistency I have maintained the same bins for the analysis with minimum and maximum temperatures. In addition the distribution of hours exposed to the four bins is demonstrated separately for cattle-owner sample and buffalo-owner samples in Figures 1 and 2 respectively.

3 Empirical Analysis

3.1 MaxT, MinT Over 30 Days

I begin the empirical analysis by estimating the marginal impact of an increase in the maximum temperature faced by the animals in the last 30 days. I estimate the following equation:

$$Y_irt = \beta_0 + \beta_1 Temp_{rt} + \beta_2 Rain_{rt} + \beta_3 X_{irt} + \delta_r + \tau_t + \epsilon_{irt} \quad (1)$$

Since the data is at the household level the dependent variable Y_irt refers to logarithm of average milk yield for household i, in region r, at time t. The time refers to the date of survey for the NSS for that particular household. The coefficient of interest is β_1 which measures the marginal effect of Temp. This variable measures the maximum/minimum temperature experienced in the region where household i is situated in the last 30 days starting from the date of survey t. I control for household size, mean percapita consumption expenditure, religion, caste, and source of primary income (own-farm, casual labour, regular agricultural labour, or livestock). Note that this sample is entirely rural. The specifications estimated explore different combinations of region and time fixed effects, but the preferred specification is with district and month fixed effects. The independent variables have been scaled so that coefficients can be interpreted as percentage change. The results are reported in Table 4 for average maximum temperature as the main independent variable. The magnitude of the impact of an increase in maximum temperature by $1°c$ ranges from fall in milk yield of about 1% to 2.4% for cattle and correspondingly from 0.4% to 2.14% for buffaloes. The effect is statistically significant apart from the specification that uses district-month fixed effects. This is most likely due to the variation in temperature getting absorbed by the fixed effects almost completely. The preferred specification with month and district fixed effects is in column 5 and 10 which shows the highest impact of 2.4% and 2.14% respectively. The results for buffaloes is slightly weaker in terms of statistical significance which may be due to the smaller sample size. Addition of household level controls do not lead to any significant changes.

Results using average minimum temperature in the 30 days prior to the survey are reported in Table 5. Qualitatively these results are very similar to those reported for maximum temperature in table 4, however the size of the effect is larger. For cattle the fall in milk yield ranges from about 1% to 3.6%, and buffaloes the corresponding figures range from 0.5% to 2.5%. This is in line with previous findings which indicate that minimum temperature is likely to have a greater impact as in most cases maximum temperatures are already beyond the comfort levels of the animals and any further increase may not produce drastic effects (Sirohi and Michaelowa, 2007).

3.2 Hours of Exposure Over 30 Days

Although I see strong negative effect of maximum temperature on yields, this effect is likely to be an under-estimation. Effect of heat on organisms (both plants and animals) is known to be non-linear. For example the literature on heat stress on dairy animals points out that in the temperature range above 25 degrees centigrade the animals experience heat stress in tropical regions of the world (Das et al., 2016). As such the impact of an increase in temperature beyond such a threshold is likely to result in much bigger impacts. In the literature such effects are usually studied by looking at the impact of number of hours exposed to different temperature ranges. The use of hourly exposure to different temperature intervals was introduced to the literature in the context of the impact of temperature on agricultural yields by Schlenker and Roberts (2009). The same was also used in other contexts, for example Blom et al. (2022) used the same method to measure the effect of heat exposure on child health outcomes. In this paper I adopt this method. Assuming that temperatures move between the minimum and maximum temperature in a day according to a sine curve, I can calculate the number of hours exposed to any temperature range. I break the range of temperature into 4 intervals starting with below 15 degree centigrade and then each subsequent interval covering 10 degrees more till I reach 35 degree centigrade. All exposure to temperatures above 35 are put in a separate bin. The distribution of hours exposed to these 4 bins can be seen in Figures 1 and 2 for cattle and buffaloes respectively.

Using these bins I run the following regression:

$$Y_irt = \beta_0 + \sum_{j=2}^{4} \beta_{1j} Exp_{jrt} + \beta_2 Rain_{rt} + \beta_3 X_{irt} + \delta_r + \tau_t + \epsilon_{irt} \quad (2)$$

In equation 2 logarithm of milk yield is regressed on a set of variables Exp_{jrt}, which represents the number of hours of exposure that the district of residence r of the household i has undergone in the temperature range represented by jth bin in the last 30 days before the date of survey. I omit the first category of exposure to temperatures below 15 degree centigrade. As such each coefficient is to interpreted as the marginal impact of an hour of exposure in the jth bin compared to the omitted bin. The specification in Equation 2 also includes a set of household controls. I use different combinations of region and time fixed effects with the preferred specification being the one with district and month fixed effects. The results of this estimation is reported in Table 6 and coefficents with 95% confidence intervals are shown for the main specification in Figure 3. The results indicate that exposure to higher temperatures have increasingly greater negative impact on yield for both cattle and buffaloes. For cattle the impact is higher. For a single hour of extra exposure to temperatures above 35 degree centigrade in the last 30 days the negative effect on yield is 0.1%. For buffaloes the corresponding number is 0.09%.

3.3 Robustness

The coefficients estimated above are robust to various combinations of spatial and seasonal controls. Spatial controls can inserted using state, region, or district level fixed effects. The region is a geo-climatic subdivision which are a part of the NSS datasets. Regions are typically smaller than states but larger than districts. Since this is a cross-section the time dimension can be controlled using months, or sub-rounds (3 month periods starting with January-March to October-December). Since our temperature variation is at the district×date of survey level, it is theoretically possible to include month×district fixed effects, however, I see that this specification absorbs almost the entire variation in temperature leading to imprecisely measured coefficients and very low F-statistics (see columns 4 and 9 in Tables 5, 4, and 6). For example, more than 99% of variation in maximum temperature of the last 30 days is explained by a regression specification with month×district fixed effects and the full set of household controls. As such my preferred set of fixed effects have district and month fixed effects inserted separately. I also show that my coefficients are robust to the inclusion of various household level controls. These include controls for household size, percapita consumption expenditure, religion, caste categories, and dummies for primary income source (own-farm, casual labour, regular agricultural labour, or livestock). These controls aim to factor in the household/farmer's ability to shield their milch animals from heat shock by having access to resources (individual or community), and knowledge or being motivated to do so (for example if primary income source is livestock).

3.3.1 Day Bins

I also use a second specification to investigate the relationship between temperature and milk yields. In this I use bins of temperature as before, but the main dependent variable is the count of days when average maximum/minimum temperature in the last 30 days fall in the bins. The regression equation is as follows:

$$Y_irt = \beta_0 + \sum_{j=2}^{4} \beta_{1j} Exp_Days_{jrt} + \beta_2 Rain_{rt} + \beta_3 X_{irt} + \delta_r + \tau_t + \epsilon_{irt} \tag{3}$$

Equation 3 is similar to Equation 2 above except that the main variable of interest

$Exp_{D}ays_{jrt}$ refers to the number of days in the 30 days before the date of survey, that maximum/minimum temperature in region r was in the jth bin. The construction of the bins are the same as in Equation 2 and the omitted category is temperatures less than 15 degree centigrade. As such, the coefficients β_{1j} may be interpreted as percentage change in yield when one day falls in bin j compared to the omitted bin. The results are reported in Table 7 and appear to be qualitatively similar to those reported for hourly exposure in Figure 3. The marginal impact of a day with maximum temperature in the bin above $35°c$ is a fall in yield of 0.8% for cattle and 1.5% for buffaloes (table 7 column 2 and 4). The pattern of bigger negative effect with higher temperature bins is also maintained in this specification similar to the earlier estimation with hourly bins. For the lower bin of 15 to 25 degrees the impact is usually insignificant or positive (see Table 7 column 4). On the other hand, for minimum temperature bins the magnitude of the coefficients do not change with higher temperature bins, remaining more or less close to 1%. However the impact is negative and significant for the lower temperature bins as well. The highest temperature bin is absent for minimum temperature.

3.3.2 Placebo: Randomly Assigned Weather

Following Blom et al. (2022) I conduct a robustness check by randomly assigning weather variable outcomes to the households in my sample. I select the hourly exposure outcomes (number of hours exposed to the 4 bins in the last 30 days) randomly with replacement from my sample and assign them to households. With this constructed weather variable I re-run the specification in equation 2. The results are reported in table 8. None of the placebo specifications show any significant effect of hourly exposure.

4 Conclusion

The analysis presented in the last section shows that exposure to higher temperatures for a sustained period leads to significant negative impact on milk yield. I demonstrate this using hourly exposure to different temperature ranges in the last 30 days before the date of survey. This specification allows the us to see the impact of exposure to higher temperatures where the animals are pushed out of their comfort zone. I find that for every hour of exposure to temperatures above 35 degree centigrade milk yield falls by 0.1%. and 0.09% for cattle and buffaloes respectively. For an average Indian farmer, who will face roughly 80 hours above 35 degree centigrade in a 30 day period (see figure 1), this amounts to a loss in daily milk yield of 7-8%. For an average buffalo owner with one animal in milk this would amount to a loss in monthly income roughly of INR 375 or 4 USD.

In order to understand the economic significance of these estimates I look at an alternative future scenarios with 1° rise in temperatures throughout the country. Assuming the numbers and spatial distribution of animals to be constant I can calculate the predicted milk yield using my estimates. I predict milk yields for both animal types for all milk farming households in my sample, but using hourly exposure to temperature bins data from the alternate scenario. I find that compared to current levels milk yield for cattle and buffaloes are predicted to fall by more than half a litre (2.64 to 1.84 for cattle and 3.2 to 2.6 for buffaloes) for the alternate scenario with 1° rise in temperatures. This amounts to a massive 30% fall for cattle and a slightly smaller 18% drop for buffaloes. Using the estimate of per unit value of milk as estimated from this data and the average number of animals in milk, I calculate that the loss amounts to slightly more than INR 740 and INR 900 per month for cattle and buffalo milk producing households respectively[3]. The loss in milk yields may also lead to loss in terms of nutrition. For the rural agricultural households milk is a major source of protein. The loss in protein sourced from the milk percapita per day is about 4.73 grams

[3]Countrywide estimate of milk price from this survey is INR 43 and INR 56 per litre for cattle and buffaloes respectively.

of protien for cattle and 5.76 grams for buffalo milk producing households[4]. According to general estimates of percapita protein consumption requirements this is almost 10% of the requirement. Thus it appears that the burden of just single degree rise in temperature on the average rural household will be quite substantial.

The model estimated in equation 1 may not be ideal for prediction, as such, the figures presented above should be taken as indicative evidence. However, the size of the effect estimated is likely to be much more reliable. As a second exercise looking at the future I calculate hourly exposure to the 4 bins in 3 alternate scenarios with 1°, 2°, and 3° rise in temperatures. For each scenario I estimate the impact of the mean level of heat exposure to temperatures above 35 degree centigrade. The results are shown in figure 4. I find that the effect almost doubles from current to the 3° rise scenario going from slightly higher than 8% to more than 16%. While conducting this exercise I assume that the marginal impact of an hour above 35° as estimated in Section 3 is stable over time and other covariates included in the specification remain constant. I also assume that the spatial distribution of animal owners and the impact of seasons remains the same over time.

In conclusion, this study finds significant negative impact of heat exposure of both cattle and buffaloes, to temperatures above 25°c, with higher impact for temperatures above 35°c. This is particularly concerning as rising global temperatures imply that in future exposure to such high temperatures would increase exacerbating the losses. For a 1°c rise in global temperature the loss would exceed 10% whereas for a 3°c rise the loss would be cross 16% for the average farmer. This is likely to be a heavy burden on the relatively poor farmer households who rely on milk produced at home for nutrition as well as for income. In many rural households in India milk is used to supplement children's diets, loss in milk production from household animals may lead to adverse impact on child nutrition and as such on child health outcomes (Blom et al., 2022).This study sheds light on a yet unexplored aspect of global warming with disproportionate impact on a large, relatively poor, and vulnerable

[4] I am using 40gms of protein per litre of milk as the conversion factor. This is from the tables provided by NSS in its consumption survey reports.

population.

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5 Tables and Figures

Table 1: Descriptive Statistics Dairy Operations: NSS 71st Round

	(1) **Cattle**	(2) **Buffalo**
Nos. in Herd	2.57	2.52
	(0.03)	(0.03)
Nos. in-milk	0.74	0.9
	(0.012)	(0.017)
Milk Qty. (ltrs. 30 days)	51.07	59.62
	(1.51)	(2.1)
Milk Yield	2.58	3.22
(ltr. per day per Animal)	(0.048)	(0.067)
N	19872	10144

Figures reported above are estimated means of the respective variables using sampling weights and stratification as provided by NSS. Standard errors are in parenthesis. Figures in columns 1 and 2 refer to the sample who report having at least one cow or buffalo respectively.

Table 2: Descriptive Statistics Household Characteristics: NSS 71st Round

	(1) **Full**	(2) **Cattle**	(2) **Buffalo**
Hhld. Size	4.50	5.13	5.55
	(0.021)	(0.031)	(0.042)
Hindu (1/0)	0.84	0.89	0.91
	(0.004)	(0.005)	(0.006)
Islam (1/0)	0.10	0.07	0.05
	(0.004)	(0.005)	(0.004)
ST	0.13	0.18	0.08
	(0.004)	(0.007)	(0.006)
SC	0.21	0.16	0.15
	(0.005)	(0.007)	(0.009)
OBC	0.44	0.44	0.53
	(0.006)	(0.009)	(0.011)
MPCE	1922.32	1781.77	1954.95
	(14.298)	(13.971)	(18.932)
Primary Income Source			
Own Cultivation	0.40	0.63	0.69
	(0.005)	(0.008)	(0.01)
Livestock	0.01	0.03	0.03
	(0.001)	(0.002)	(0.003)
Agr. Reg. Wage	0.02	0.01	0.01
	(0.001)	(0.002)	(0.002)
Agr. Cas. Labour	0.14	0.09	0.06
	(0.004)	(0.005)	(0.005)
N	52222	19872	10144

Figures reported above are estimated means of the respective variables using sampling weights and stratification as provided by NSS. Standard errors are in parenthesis. Figures in columns 2 and 3 refer to the sample who report having at least one cow or buffalo respectively.

Table 3: Descriptive Statistics Weather Variables

	(1)	(2)	(2)
	Full	**Cattle**	**Buffalo**
MaxT	32.43	32.24	32.05
	(0.12)	(0.15)	(0.24)
MinT	20.28	19.75	19.07
	(0.15)	(0.2)	(0.28)
Rain	3.4	3.34	2.61
	(0.12)	(0.14)	(0.14)
MaxT No. of Days out of 30			
Less than 15°	0.1	0.09	0.11
	(0.12)	(0.02)	(0.03)
15 - 25°	3.05	3.36	4.84
	(0.14)	(0.18)	(0.31)
25 - 35°	15.65	15.67	12.85
	(0.12)	(0.27)	(0.32)
above 35°	10.82	10.51	11.51
	(0.24)	(0.31)	(0.42)
MinT No. of Days out of 30			
Less than 15°	6.33	7.29	8.46
	(0.23)	(0.32)	(0.43)
15 - 25°	13.69	13.4	11.6
	(0.22)	(0.29)	(0.37)
25 - 35°	9.59	8.95	9.26
	(0.27)	(0.33)	(0.45)
above 35°	0.01	0.01	0
	(0.00)	(0.00)	(0.00)
N	52222	19872	10144

Figures reported above are estimated means of the respective variables using sampling weights and stratification as provided by NSS. Standard errors are in parenthesis. Figures in columns 2 and 3 refer to the sample who report having at least one cow or buffalo respectively. All figures are rounded to two decimal points.

Table 4: Effect of Max Temperature on Milk Yield

	Cattle					Buffalo				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
MaxT (30 day)	-1.635***	-0.954**	-2.441***	0.367	-2.427***	-1.136***	-0.423	-2.144***	1.158	-2.142***
	(0.347)	(0.377)	(0.525)	(2.100)	(0.529)	(0.333)	(0.405)	(0.612)	(2.482)	(0.618)
Rain (30 day)	-1.087***	-0.399	-1.266***	0.130	-1.262***	-0.249	-0.0291	-0.0845	-1.782	-0.0271
	(0.278)	(0.249)	(0.374)	(0.982)	(0.372)	(0.446)	(0.460)	(0.662)	(1.342)	(0.678)
Region	Y	Y	N	N	N	Y	Y	N	N	N
District	N	N	Y	Y	Y	N	N	Y	Y	Y
Month	N	N	Y	Y	Y	N	N	Y	Y	Y
Sub-round	Y	Y	N	N	N	Y	Y	N	N	N
Month×*District*	N	N	N	Y	N	N	N	N	Y	N
Sub-Round ×*Region*	N	Y	N	N	N	N	Y	N	N	N
Hhld. Controls	N	N	N	N	Y	N	N	N	N	Y
N	10741	10737	10712	10201	10712	4924	4914	4874	4550	4874
r2	0.303	0.332	0.420	0.610	0.427	0.174	0.194	0.307	0.511	0.318
F	12.76	3.558	11.33	0.0195	8.877	6.529	0.725	6.504	1.599	6.117

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Dependent variable is logarithm of milk yield per animal per day in liters. Independent variables are scaled so that coefficients can be interpreted as percentage change. Standard errors are clustered at district level. There are 594 and 413 clusters for the cattle and buffalo specifications respectively

Table 5: Effect of Min Temperature on Milk Yield

	Cattle					Buffalo				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
MinT (30 day)	-1.813***	-0.909**	-3.685***	0.823	-3.633***	-1.323***	-0.526	-2.529***	-0.852	-2.566***
	(0.388)	(0.371)	(0.746)	(2.227)	(0.750)	(0.389)	(0.463)	(0.910)	(2.925)	(0.923)
Rain (30 day)	-0.565**	-0.0873	-0.905***	0.101	-0.902***	0.346	0.184	0.320	-2.078*	0.374
	(0.232)	(0.237)	(0.322)	(0.950)	(0.320)	(0.382)	(0.386)	(0.630)	(1.212)	(0.642)
Region	Y	Y	N	N	N	Y	Y	N	N	N
District	N	N	Y	Y	Y	N	N	Y	Y	Y
Month	N	N	Y	Y	Y	N	N	Y	Y	Y
Sub-round	Y	Y	N	N	N	Y	Y	N	N	N
Month×*District*	N	N	N	Y	N	N	N	N	Y	N
Sub-Round ×*Region*	N	Y	N	N	N	N	Y	N	N	N
Hhld. Controls	N	N	N	N	Y	N	N	N	N	Y
N	10741	10737	10712	10201	10712	4924	4914	4874	4550	4874
r2	0.303	0.331	0.422	0.610	0.429	0.174	0.194	0.306	0.511	0.317
F	12.25	3.168	12.80	0.0754	9.449	6.725	0.857	4.254	1.470	5.831

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Dependent variable is logarithm of milk yield per animal per day in liters. Independent variables are scaled so that coefficients can be interpreted as percentage change. Standard errors are clustered at district level. There are 594 and 413 clusters for the cattle and buffalo specifications respectively

Table 6: Effect of Exposure to Different Temperatures on Milk Yield: Hourly Exposure

	Cattle					**Buffalo**				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
15 - 25°	-0.0360***	-0.0264*	-0.0352*	-0.00727	-0.0346**	-0.0307*	-0.0361**	-0.0495	-0.0847	-0.0440
	(0.0131)	(0.0145)	(0.0180)	(0.0549)	(0.0176)	(0.0162)	(0.0177)	(0.0322)	(0.0621)	(0.0324)
25 - 35°	-0.0368***	-0.0179	-0.0785***	0.0677	-0.0784***	-0.0376***	-0.0173	-0.0711***	-0.0178	-0.0726***
	(0.0108)	(0.0112)	(0.0202)	(0.0690)	(0.0203)	(0.0124)	(0.0144)	(0.0262)	(0.0853)	(0.0262)
Above 35°	-0.0763***	-0.0565***	-0.103***	0.0213	-0.101***	-0.0441**	-0.0259	-0.103**	0.00409	-0.0990**
	(0.0197)	(0.0187)	(0.0288)	(0.0971)	(0.0288)	(0.0184)	(0.0191)	(0.0415)	(0.109)	(0.0414)
Rain Avg. 30 Day	-0.00895***	-0.00401	-0.0105***	0.00151	-0.0105***	0.00222	0.00107	0.00174	-0.0166	0.00221
	(0.00281)	(0.00271)	(0.00346)	(0.0100)	(0.00343)	(0.00469)	(0.00491)	(0.00651)	(0.0130)	(0.00662)
Region	Y	Y	N	N	N	Y	Y	N	N	N
District	N	N	Y	Y	Y	N	N	Y	Y	Y
Month	N	N	Y	Y	Y	N	N	Y	Y	Y
Sub-round	Y	Y	N	N	N	Y	Y	N	N	N
Month×*District*	N	N	N	Y	N	N	N	N	Y	N
Sub-Round ×*Region*	N	Y	N	N	N	N	Y	N	N	N
Hhld. Controls	N	N	N	N	Y	N	N	N	N	Y
N	10741	10737	10712	10201	10712	4924	4914	4874	4550	4874
r2	0.303	0.332	0.420	0.610	0.427	0.175	0.196	0.307	0.511	0.318
F	8.080	3.503	5.865	0.321	7.766	4.081	1.651	2.744	1.423	5.254

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Dependent variable is logarithm of milk yield per animal per day in litres. Each coefficient is the marginal impact of an hour exposure to temperatures in the corresponding intervals, in the last 30 days. All coefficients indicate percentage change. Standard errors are clustered at distric level. There are 576 and 356 clusters for the cattle and buffalo specifications respectively

Table 7: Effect of Exposure to Different Temperatures on Milk Yield: Day Bins

	Cattle		Buffalo	
	Min	Max	Min	Max
	(1)	(2)	(3)	(4)
15 - 25°	-1.056***	0.775*	-0.887**	0.186
	(0.263)	(0.452)	(0.360)	(0.518)
25 - 35°	-1.200***	-0.205	-0.982**	-0.830
	(0.359)	(0.435)	(0.432)	(0.603)
Above 35°	-	-0.786*	-	-1.553**
	-	(0.464)	-	(0.693)

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Dependent variable is logarithm of milk yield per animal per day in litres. Each coefficient is the marginal impact on dependent variable (percentage change) of a days exposure to temperatures in the corresponding intervals, in the last 30 days compared to the omitted category (less than 15°). Note that the last category (above 35°) is absent for minimum temperature as hardly any day has average minimum temperature in that category. All regressions include full household controls, district, and month fixed effects. Standard errors are clustered at district level. There are 576 and 356 clusters for the cattle and buffalo specifications respectively

Table 8: Placebo: Randomly Assigned Hourly Exposure

	Cattle		Buffalo	
	Main	Placebo	Main	Placebo
	(1)	(2)	(3)	(4)
15 - 25°	-0.0346**	-0.00112	-0.0440	-0.00705
	(0.0176)	(0.00708)	(0.0324)	(0.0105)
25 - 35°	-0.0784***	0.000806	-0.0726***	0.00677
	(0.0203)	(0.00513)	(0.0262)	(0.00627)
Above 35°	-0.101***	-0.00614	-0.0990**	-0.0127
	(0.0288)	(0.00810)	(0.0414)	(0.0111)

Standard errors in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Dependent variable is logarithm of milk yield per animal per day in litres. Each coefficient is the marginal impact on dependent variable (percentage change) of an hour's exposure to temperatures in the corresponding intervals, in the last 30 days compared to the omitted category. Columns 2 and 4 show the placebo regressions for cattle and buffalo owners respectively. All regressions include full household controls, district, and month fixed effects. Standard errors are clustered at district level. There are 576 and 356 clusters for the cattle and buffalo specifications respectively

Figure 1: Distribution of Hourly Exposure to Temp Bands in 30 days(cattle)

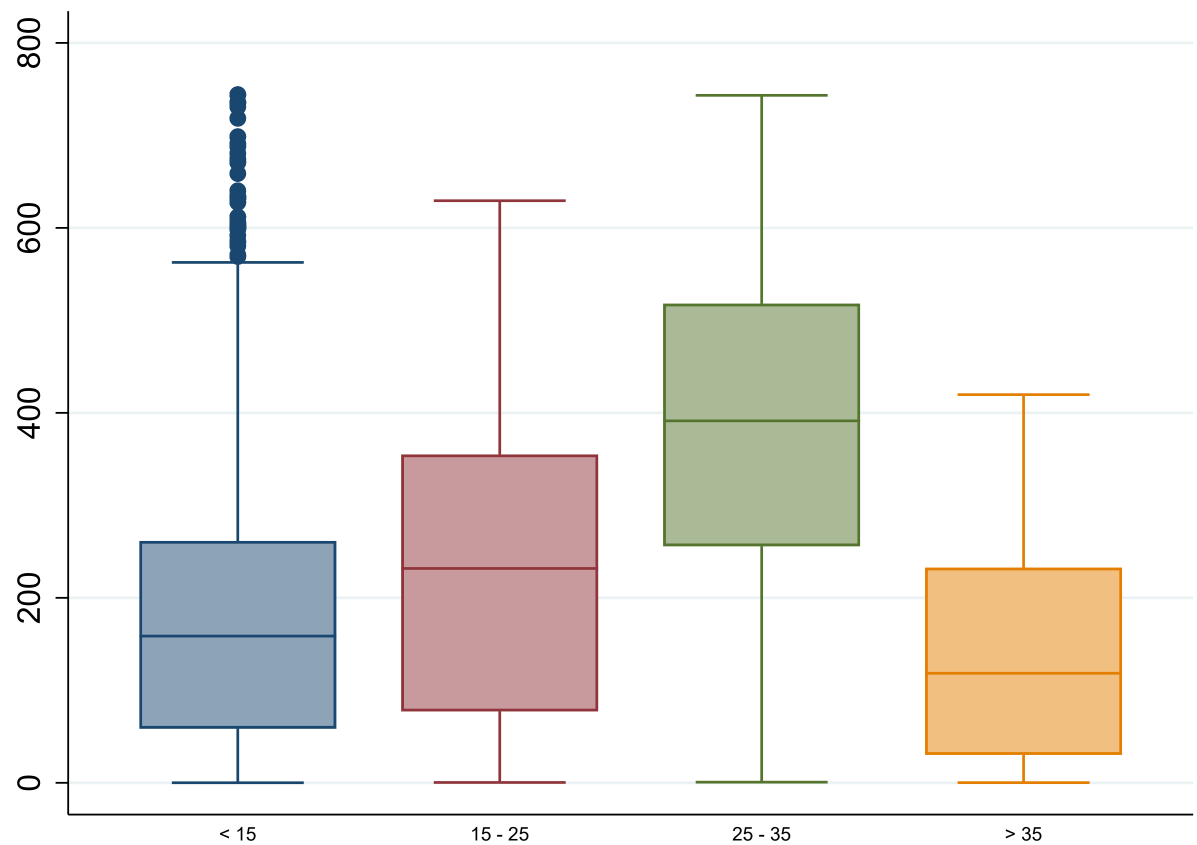

Figure 2: Distribution of Hourly Exposure to Temp Bands in 30 days(buffalo)

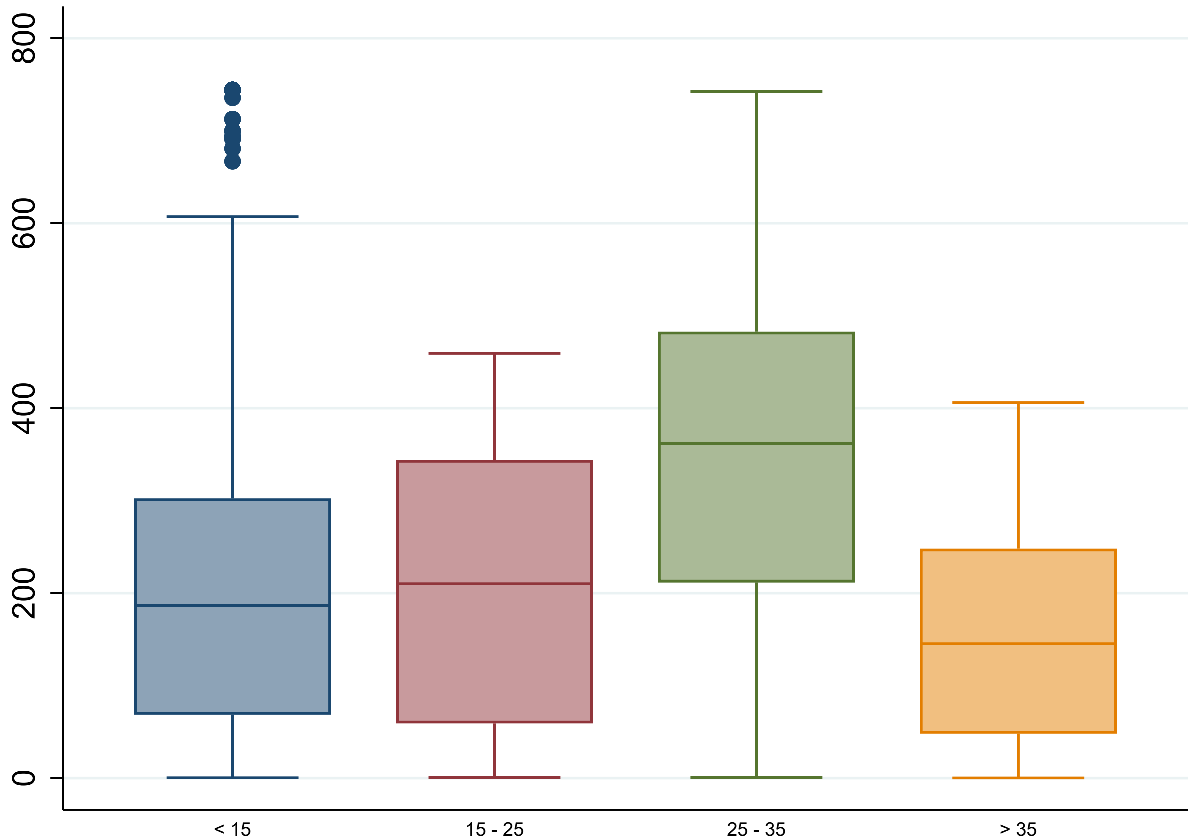

Figure 3: Yield and Exposure to Temp Bands.

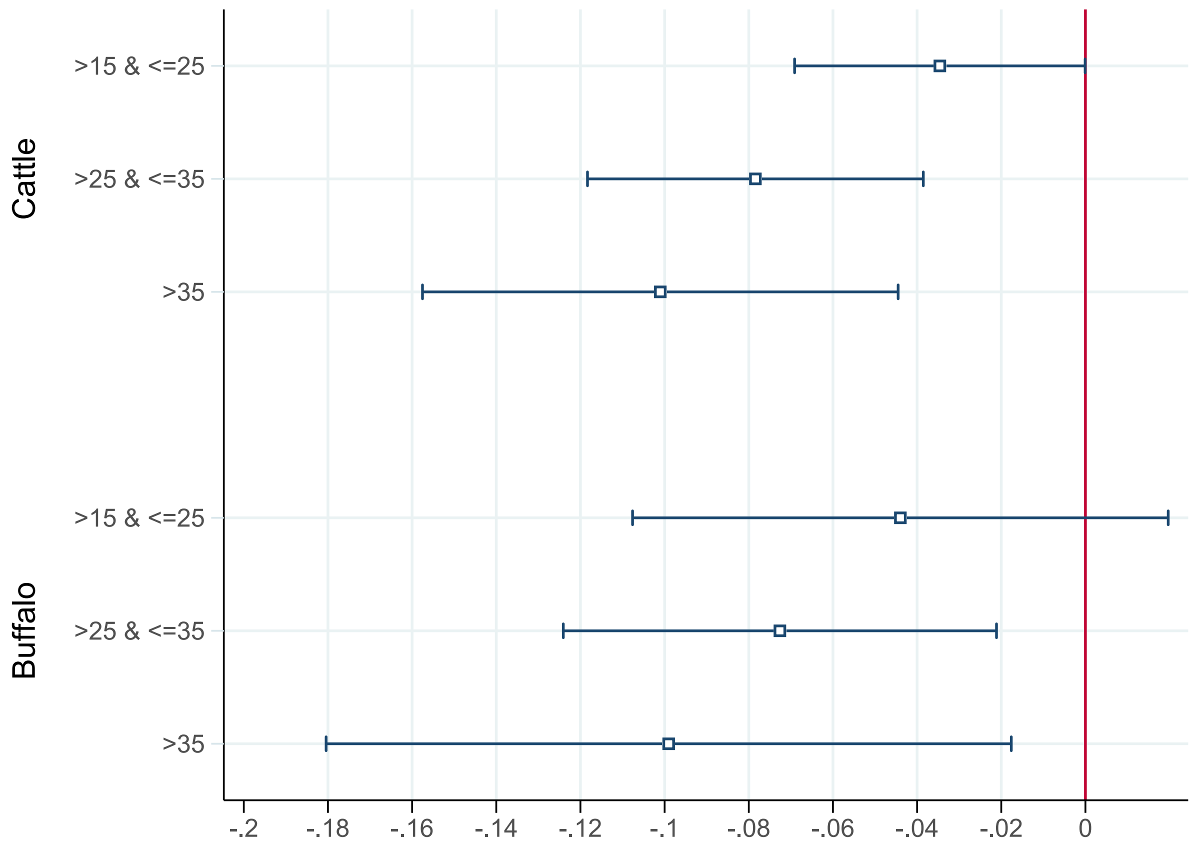

Figure 4: Impact of Average Exposure to Temperature Above 35° for Alternate Scenarios