Ramadan Fasting and Agricultural Output*

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Abstract

Religious practice is widespread and disproportionately prevalent among the world's poor, yet its contemporaneous economic costs are difficult to quantify at a micro-level given the challenges of finding credible, exogenous variation in observance. This paper provides well-identified estimates of this cost in a large low-income population, using granular production data from agriculture and variation in the timing of the observance of Ramadan fasting among India's Muslim minority. Because Ramadan follows a lunar calendar, its overlap with the labor-intensive sowing and harvesting periods varies across crops within a district-year, across districts within a crop-year, and over time for a given crop-district pair as the holiday cycles through the year. Using this variation in a differences-in-differences-in-differences design, I find that full overlap between Ramadan and sowing or harvesting periods in a given year produces a contemporaneous reduction in agricultural output of 2.0 to 2.9% in quantity and 3.4 to 4.7% in value, or roughly 1% of India's agricultural GDP annually. The effect is concentrated in districts with an above-median Muslim population share. There is little evidence that farmers offset this predictable shock through meaningful changes to other inputs such as land, draft labor, or fertilizer. Direct evidence rules out reduced labor supply as a driver of the output decline. However, survey data show a substantial decline in caloric intake during Ramadan, and additional tests, including the persistence of output declines beyond the holiday itself, are consistent with reduced caloric intake as an important contributor to the productivity decline.

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1 Introduction

Religion is an important force in the lives of the majority of the world's population. Roughly 85% of the world's population expresses some religious belief, 54% state religion is very important in their lives, and nearly half of the global adult population spends time on religious activities daily (Pew Research Center, 2017, 2018). Although widespread, religious practice is disproportionately prevalent among, and central to, the lives of the world's poor, providing meaning and community to billions (Pew Research Center, 2019). Yet this practice may also have costs. These costs are notoriously difficult to quantify at a micro level: doing so convincingly requires a large-scale, economically important setting and a source of variation in observance that is plausibly exogenous to other economic conditions. This paper brings these components together, studying the observance of Ramadan fasting among India's Muslim minority in the context of agricultural production, a sector central to the livelihoods of the rural poor.

Ramadan is observed by many of the world's nearly two billion Muslims every year, including the 172 million Muslims in India (Directorate of Census Operations, 2011). It is observed via a month-long daylight fast whose timing follows the lunar calendar and cycles through the solar year over roughly three decades. Agricultural cropping cycles vary systematically across crops and across districts with differing climates, so the overlap between Ramadan and the labor-intensive sowing and harvesting periods of a given crop varies along three distinct dimensions. The first source of variation, generated by the fact that Ramadan cycles throughout the calendar year, is variation for a given crop-district combination over time. The second, variation among crops within a district-year, is the result of natural variation in cropping cycles for different plants. Finally, different climatic patterns across India's large geography generate variation in cropping cycles between districts, resulting in spatial variation for a given crop within a year. I use this variation in a differences-in-differences-in-differences design at the crop-district-year level, with a rich set of fixed effects that absorb the great majority of plausible confounds.

I find that full overlap between Ramadan and the sowing or harvesting season reduces agricultural output by 2.0 to 2.9% in quantity and 3.4 to 4.7% in value, corresponding to roughly 1% of India's agricultural GDP, and 0.5% of overall GDP between 1956 and 1987. Because Muslims are a minority of the rural population — roughly 10% on average — during the period covered by my data, these aggregate declines imply a substantially larger cost per fasting individual: a decline in productivity of 20 to 40% during the month of observance.

Building on these average estimates, I next examine heterogeneity in Ramadan's impact and demonstrate that the production declines are driven by districts with a larger concentration of Muslims. This heterogeneous effect, with little or no decline among districts with few Muslims and large declines in districts with an above median Muslim population, supports the conclusion that Ramadan, rather than other spurious factors, drives the production declines.

I next examine whether farmers offset this predictable shock through other agricultural inputs — land under cultivation, draft animal labor, or fertilizer use — and find little evidence that they do with the exception of small increases in fertilizer use during sowing periods that overlap with Ramadan. I also provide evidence against substitution across crops by aggregating production to the district-year level, so that any shift toward unaffected crops would show up as an offsetting gain. The yields declines in this analysis are statistically indistinguishable from those estimated at the crop level. The lack of adjustment does not necessarily reflect a lack of awareness among farmers. My data are recorded at the district level, and Muslim agricultural labor in this setting is typically dispersed across many employers,[1] so the shock to any single farm's realized labor force may be small even if the underlying productivity loss per fasting worker is large. Moreover, if seasonal agricultural labor markets are tight during sowing and harvesting, it may be privately optimal for farmers to continue hiring available workers at reduced productivity rather than leave land fallow, switch crops, or forgo labor altogether. Liquidity constraints and missing markets could further limit adjustment even where farmers are aware of the decline and would prefer to respond.

Finally, I explore several candidate channels through which fasting might lower productivity: reduced caloric intake, sleep disruption, dehydration, and time reallocated to religious or social obligations. Using survey data from the ICRISAT village studies and the National Sample Survey and a differences-in-differences approach, I find no reduction in labor supply or earnings among Muslims during Ramadan. Consumption data from the National Sample Survey instead shows a substantial decline in caloric intake, roughly 600 calories per person per day during the holiday. Evidence on sleep and dehydration is more indirect, but suggests little role for either channel. First I draw on the physiological literature to argue that sleep and hydration deficits of the magnitude expected during Ramadan are unlikely to meaningfully impair physical labor. Additionally, I conduct a direct test exploiting local weather conditions that increase perspiration. I augment the main specification with a main effect for these conditions, since they may directly affect agricultural output, and an interaction be-

[1] Muslims are, and have historically been, significantly less likely to own land than non-Muslim populations (Prime Minister's High Level Committee, 2006). Fewer than 10% of districts have a Muslim population share above 20%.

tween the conditions and the Ramadan overlap variables, which tests whether output declines differentially when weather that leads to higher perspiration rates coincides with the holiday. While these climatic conditions have direct impacts on output, I do not find a differential effect of these climatic conditions duration Ramadan, arguing against a dehydration channel. Finally, because caloric deficits, unlike sleep loss or dehydration generate productivity effects that persist beyond the period of restriction itself, I test whether production remains depressed in the weeks following Ramadan when overlap with sowing or harvesting continues into that period (Keys et al., 1950; Schofield, 2018; Jéquier and Constant, 2010; Van Dongen et al., 2003). I find evidence of some persistence in declines beyond the holiday, consistent with a caloric channel. Together, these tests provide suggestive evidence that reduced caloric intake is an important contributor to the observed declines in output.

This paper relates to two broad literatures. First, it builds on a growing literature in economics shows that religious belief and practice shape economic behavior and outcomes. This work spans a wide range of outcomes, from educational performance to bank liquidity to political cohesion, exploiting variation in the timing and intensity of religious observance — most often the shifting timing of Ramadan itself (Hornung et al., 2023; Raz, 2023; Aksoy and Gambetta, 2022). Also central to this literature is a longstanding interest in economic growth and productivity, starting with early cross-country work relating religiosity to growth (e.g., (Barro and McCleary, 2003; McCleary and Barro, 2006)). Closest to my paper is Campante and Yanagizawa-Drott (2015), who show that longer Ramadan fasts reduce economic growth across countries, identified largely from countries in the Middle East and North Africa and Montero and Yang (2022) who show that Mexican municipalities whose (fixed, centuries-old) patron saint festival dates coincide with the agricultural calendar experience less long-run economic development.

My identification and setting differ in important ways from these papers. I exploit overlap between Ramadan's timing and the agricultural calendar in a triple-difference design, among a poor, rural, religious-minority population in India. This approach allows me to estimate the average effect of observing Ramadan at all — the extensive margin of observance — on contemporaneous agricultural output. This differs from Campante and Yanagizawa-Drott (2015), who examine intensive-margin adjustments in fasting duration and their effect on long-run growth, and from Montero and Yang (2022), who examine the impact of festivals on long-run economic development.

Additionally, in contrast to both papers, in my setting, Muslims are a small minority: they average only about 10% of the district population. This means that the surrounding economy operates largely as usual, isolating the effect on individuals rather than broader shifts in the economy such as adjustments to business hours and market activity. In this vein, my more granular setting and data also allows me to provide suggestive evidence on the channels through which the effects operate, which are likely quite different from those in the Muslim-majority, and often considerably wealthier, countries driving the identification in Campante and Yanagizawa-Drott (2015) or the religious homogeneity of Mexico in Montero and Yang (2022).

Second, this paper also relates to a body of work examining the economic consequences of Ramadan fasting through a different channel: the long-run effects of maternal fasting in utero on later-life human capital and economic outcomes (Almond and Mazumder, 2011; Van Ewijk, 2011; Majid, 2015). These studies establish that nutritional shocks tied to Ramadan can have persistent consequences beginning before birth, but do not explore whether comparable contemporaneous effects operate among working-age adults.

This paper takes up that question directly, while also contributing to a broader literature on caloric intake and productivity. Older observational estimates rely on non-experimental variation — from cross-sectional differences in food prices and household characteristics to panel variation net of individual fixed effects — that are subject to a range of potential confounds (Strauss, 1986; Deolalikar, 1988). Experiments that manipulate caloric intake directly avoid these concerns but typically do so in small samples and researcher-constructed settings such as supplementing road construction workers, sugarcane cutters, or rickshaw drivers, raising concerns about demand effects, statistical power, and generalizability (Immink and Viteri, 1981a,b; Wolgemuth et al., 1982; Schofield, 2018). This paper's setting addresses these concerns simultaneously: the change in caloric intake is neither chosen by a researcher nor experienced by participants as part of a study, and the resulting variation in overlap between Ramadan and the agricultural calendar recurs across 32 years and hundreds of districts, rather than relying on a single intervention in a narrow sample. Because data limitations in the natural experiment make it challenging to fully separate caloric intake from the other channels discussed below, the resulting evidence on this specific mechanism is necessarily suggestive rather than definitive. Nonetheless, these results speak to a relationship for which well-identified field evidence remains uncommon.

The remainder of the paper proceeds as follows. Section 2 provides background on Ramadan, Indian agriculture, and the data used in the main analysis. Section 3 presents the triple-differences estimates of the impact of Ramadan on agricultural production and the heterogeneity of this effect by district Muslim population share. Section 4 examines potential margins of adjustment in agricultural inputs. Section 5 explores candidate channels through which the productivity decline may operate. Section 6 concludes.

2 Background

2.1 Ramadan

Ramadan is a month-long Muslim holiday observed primarily through fasting during daylight hours. Fasting includes abstinence from both food and liquids and is typically considered obligatory for practicing Muslims with the exception of children, the elderly, individuals who are ill, infirm, or traveling, and women who are pregnant or breast feeding. Muslims are also expected to abstain from smoking, sexual relations, and swearing during daylight hours throughout the holiday. In addition, there is an added emphasis on prayer, reading the Koran, and charity during this time (Blackwell, 2009; Ahmad et al., 2012). The holiday is lunar, shifting by roughly eleven days per year, and cycling through the calendar year approximately once every 30 years. Ramadan is followed by Eid, a holiday marking the end of Ramadan. During Eid, Muslims are not allowed to fast, and typically engage in a special prayer in a communal area, visit family and friends, and sometimes exchange gifts. Eid is a minimum of one day but can last up to three days (Blackwell, 2009).

2.2 Agriculture in India

Agriculture is a critical sector in the Indian economy. Although the share of GDP generated from agriculture has declined from 43% in 1960 to 17% in the last decade, agriculture still accounts for nearly half of employment in India (National Academy of Agricultural Sciences, 2013; World Bank, 2019). Driven in part by technology improvements during the Green Revolution, growth in this sector has been relatively rapid with a four-fold increase in real value over the same period (Food and Agricultural Organization , FAO; Evenson, 2003). India's primary crops are food grains such as rice, wheat, and millet as well as cash crops such as sugarcane, oilseeds, and peanuts. Additional details about the agricultural data used in this analysis are provided below.

2.3 Data

In order to examine the impact of Ramadan fasting on agricultural production this analysis draws on four main sources of data. First, data on agricultural production was obtained from the World Bank India Agriculture and Climate dataset compiled by Apurva Sanghi, Kavi Kumar, and James McKinsey. This dataset contains production and price information for 20 crops between 1956 and 1987 in 271 Indian districts covering 85% of the land area of India and all of the major agricultural areas, with the exception of Kerala and Assam.[2] Second, data on agricultural production cycles was generously provided by Dave Donaldson who compiled it from the 1967 Indian Crop Calendar published by the Indian Directorate of Economics and Statistics (Donaldson, 2018). This dataset includes the typical sowing and harvesting periods for 18 of the crops included in the agricultural production data at the district level. Table A.II provides additional information about the 18 crops and their cropping cycles. Third, data on the fraction of individuals in each district who are Muslim was gathered from the 1961 Indian census.[3] Finally, rainfall and temperature data were obtained from the University of Delaware monthly rainfall and temperature series (University of Delaware, 2013). Additional data sources for the supplementary analyses of channels are also outlined in Table A.I.

2.4 Empirical Strategy

In order to assess the impact of Ramadan on economic output it is necessary to measure output as related to "exposure" to the holiday that is independent of spatial or temporal confounds. In addition, in order to increase external validity, this variation should occur in an economically important industry in which production is well measured at the same "level" as the variation in the exposure to holiday.

Agricultural production offers a number of advantages in this respect. Although many industries are relatively stable across the year (i.e. manufacturing), agricultural production has significant seasonality, both for given crops and in different locations. Specifically, crops are produced at different times of the year in different locations. For example, rice may be grown in February in one district and in June in another. Given the geographic spread of India, this variation is significant, with an average standard deviation of approximately

[2] Additional information about this dataset is available online:
`https://ipl.econ.duke.edu/dthomas/dev_data/datafiles/india_agric_climate.htm`

[3] Data are taken from the 1961 census only in order to match the geographic units of the agricultural data which were reconciled to 271 consistent units over the three decades of data.

1.5 months in the timing of agricultural cycles for any given crop (Table A.II). In addition, different crops are produced at different times in the same location. For example, a district may grow rice in May and wheat in December. A typical district has a standard deviation of approximately 2.5 months and a range of roughly 9 months for the timing of crop cycles within the district (See Table A.III). This seasonality provides useful variation in "exposure" to Ramadan fasting both within and between districts. In addition to the variation related to heterogeneous cropping cycles, the fact that Ramadan is a lunar holiday and cycles throughout the calendar year can be exploited to provide temporal variation in exposure to Ramadan fasting for each crop-district combination.

In short, the overlap between Ramadan and the labor-intensive portions of the crop cycle varies across districts, crops, and years. These sources of variation allow a differences-in-differences-in-differences (DIDID) approach to identifying the impact of Ramadan on agricultural output at the district (N = 271), crop (N = 18), year (N = 32) level.

I begin by estimating Equation 1 regressing the production of crop c produced in year t in district d (q_{cdt}) on the fraction of Ramadan covered by each of the labor-intensive portions of the agricultural cycle for that crop-district-year S_{cdt} to indicate overlap with sowing and H_{cdt} to indicate overlap with harvest, as well as district-crop (θ_{cd}), district-year (γ_{dt}), crop-year (α_{ct}), crop (κ_c), district (ζ_d), and year (τ_t) fixed effects and a vector of time varying controls for rainfall and temperature relative to the cropping cycle (X_{cdt}). Further information on the time-varying controls for rainfall and temperature can be found in Section B.3. Details of the calculation of the fraction of Ramadan covered by sowing and harvesting are included in Section B.2 and example calculations are provided in Figure I. The extent of the "overlap" between Ramadan and the sowing (harvesting) seasons is measured as a fraction of Ramadan to provide a constant denominator and clearer interpretation of the coefficients of interest. Specifically, $\beta_1(\beta_2)$ multiplied by 100 corresponds to the percentage decline in total production for complete overlap between Ramadan and sowing (harvesting). Table A.IV displays the distribution of overlap between Ramadan and sowing and harvesting.

$$q_{cdt} = \beta_0 + \beta_1 S_{cdt} + \beta_2 H_{cdt} + \theta_{cd} + \gamma_{dt} + \alpha_{ct} + \kappa_c + \zeta_d + \tau_t + \beta_n X_{cdt} + \varepsilon_{ctd}. \tag{1}$$

3 Results

3.1 Agricultural Production During Ramadan

As can be seen in Table I, Column (1), total agricultural production and the value of that production decline with increased overlap between Ramadan and sowing or harvesting. Although the estimated coefficients are relatively small, they correspond to meaningful production declines. Specifically, complete overlap between Ramadan and a sowing (harvest) period would result in an overall decline in production of 2% (2.9%), though the sowing decline is only marginally statistically significant. The declines in value are both statistically significant, and appear to be even more substantial in economic magnitude at 3.4% and 4.7%, respectively. Notably, because only 10% of the population is Muslim, these overall declines in output correspond to a decline in productivity in the range of roughly 20 to 40% per fasting individual when the sowing (harvesting) season fully overlaps the holiday.

In addition to examining the impact of overlap on net production by weight across all crops, Table I displays estimates of changes in the quantity and value of production of rice – the primary staple grain and the crop of greatest total economic value in India – in Columns (3) and (4). These estimates are the same order of magnitude as the percentage declines in production for all crops, indicating that the declines are observed among economically meaningful crops and are not simply driven by marginal ones.

One potential confound in this estimation strategy is that it is possible to substitute between crops. If this occurred in response to overlap with Ramadan, the estimation would pick up not only declines in the crops with overlap but increases in other crops without overlap, biasing the coefficients. Although the declines are relatively small on net, making it unlikely that farmers would substitute between crops due to overlap with the holiday, I confirm that declines are robust to aggregation at the district-year level, which would address such a substitution strategy. These results are presented in Table II. The point estimates for aggregate declines are statistically indistinguishable from the declines estimated using the crop level data. These results suggest that substitution between crops is unlikely to be driving the observed effects and biasing the crop-district-year level estimates.[4]

Further, as shown in Table A.VI, the estimated changes are also robust to omission of

[4] Another potential concern regarding anticipation of Ramadan is that individuals could shift the timing of their labor inputs in response to anticipated changes in productivity. However, given that the timing of agricultural labor for sowing and harvest is time-sensitive, this approach is likely to be infeasible or of limited efficacy. In addition, such changes would simply under-estimate the impact of the holiday, generating a lower-bound effect.

controls for the weather (temperature and rainfall) and to examining changes in levels rather than logs.[5]

3.2 Heterogeneity in Production Declines

Despite the relatively low overall fraction of Muslims in India's population, there is substantial heterogeneity in the fraction of Muslims in each district, ranging from less than 0.1% to over 40% Muslim (Figures II and III and Table A.V provide distributional information on the fraction of the rural population that is Muslim. The sample is restricted to those districts included in the agricultural dataset). Although the geographic distribution of Muslims is non-random, the variation provides a useful heterogeneity test to confirm that the decline in production is driven by Ramadan rather than other unobserved factors. If the declines are indeed driven by Ramadan, then they should only be observed in areas in which individuals observe the holiday, or in other words, areas in which a reasonably large portion of the population is Muslim. Equation 2 tests this prediction by augmenting the previous regression with interaction terms between the overlap variables and variable(s) for the fraction of Muslims in a district M_d.[6]

$$q_{cdt} = \beta_0+\beta_1 S_{cdt}+\beta_2 H_{cdt}+\beta_3 S_{cdt}*M_d+\beta_4 H_{cdt}*M_d+\beta_5 M_d+\theta_{cd}+\gamma_{dt}+\alpha_{ct}+\kappa_c+\zeta_d+\tau_t+\beta_n X_{cdt}+\varepsilon_{ctd}. \tag{2}$$

In the non-parametric specification in Columns (1) and (2), as expected, there is no significant impact of overlap on production in below median fraction Muslim districts. However, there is a strongly negative and statistically significant impact of overlap in above median fraction Muslim districts (Table III). In Columns (3) and (4) I also estimate the net decline in production as a function of the percentage of Muslims in the district using both linear and quadratic interaction terms. As in the non-parametric specification, these results are consistent with the prediction that districts with a greater proportion of Muslims experience larger declines in output, although the positive coefficient on the quadratic term suggests that the rate of decline begins to taper slightly in districts with very large Muslim populations. However, it should be noted that support in this part of the distribution is weak, so

[5] Although not all crops are grown in all districts, it is relatively rare for districts to shift into or out of production of a crop. In addition, those districts which do shift in and out of production tend to have very low levels of production of that crop; the median production in these districts is just 7% of the median overall production.

[6] In the quadratic specification, the main effects for the fraction of Muslims term and this term squared are dropped from the estimating equation due to co-linearity with the district fixed effect.

these results should be interpreted with caution. The marginal declines in production are also presented graphically in Figure IV. This heterogeneity provides additional evidence that the observed output declines are driven by Ramadan rather than other unobserved causes.

Although these declines are substantial, they are not implausibly large. For example, even relatively small changes in labor inputs – such as broadcasting seeds rather than drill planting – may impact output substantially. In addition, there are many potential pathways through which Ramadan may impact production. For example, focusing on only the single potential pathway of caloric intake as a driver of production declines, the magnitude is consistent with a back of the envelope calibration of the "expected decline" given basal metabolic rates (BMR), the estimated declines in caloric intake, and the energy requirements of farm labor (see Section B.4 for details of this calculation and Table VI for the estimated change in caloric intake during this period). This calibration of "available labor energy" predicts productivity declines of roughly 50% as a result of the reduction in caloric intake if no energy were mobilized from fat stores. This rough calibration does not provide evidence for or against alternative explanations for the decline. However, it does suggest that despite their substantial magnitude, the observed effects are not implausibly large, especially if multiple behavioral changes occur during this period.

3.3 Summary of Results

These results demonstrate that overlap between Ramadan and sowing/harvesting has a substantial and economically meaningful negative impact on total agricultural production both in terms of quantity and value and that, consistent with Ramadan driving the declines, the impact is larger for districts with a greater percentage of Muslims.

To provide a more concrete back-of-the-envelope estimate of the aggregate losses, it is possible to weight the declines for full overlap by the expected extent of overlap. Specifically, the overlap between a crop's sowing period or harvesting period and Ramadan is approximately 0.16 in an average year (see Table A.IV). Weighting the estimated declines in value produced for full overlap of 3.4% and 4.7% (for sowing and harvesting respectively) by this average overlap generates a predicted loss of slightly less than 1% ($3.4 * .0166 + 4.7 * 0.172 = 0.86\%$) of agricultural output annually. Because agricultural output accounted for roughly half of total economic output during this period, these estimates imply a loss of 0.4 to 0.5% of GDP annually during this period due to observance of Ramadan.

4 Margins of Adjustment

The presence of such declines in production raises the question of whether farmers take steps to mitigate them. Although the declines are economically meaningful in an aggregate sense, they may be difficult to observe at an individual level given significant year to year variability in agricultural production. To provide a sense of magnitude, a typical coefficient of variation for a set of major crops in India during this time is approximately 10, and individual farmers and localities likely face even greater variation (Larson et al., 2004).[7] In addition, as discussed above, Muslim agricultural labor in this setting is typically dispersed across many employers, so the shock to any single farm's realized labor force may be small even when the underlying productivity loss per fasting worker is large, and tight seasonal labor markets may make continued hiring of available workers privately optimal even without any adjustment in inputs. With these considerations in mind, I examine a number of potential margins of adjustment: changes in crop mix, fallowing of land, substitution toward draft labor or fertilizer. Additionally, changes in hiring are explored in Section 5.

Although changes in the crop mix seem unlikely given the low percentage loss incurred in expectation and the relatively large differences in profitability of various crops, if present, these changes could threaten the identification strategy: a shift toward unaffected crops would appear as an offsetting gain in crops for which there is no overlap with Ramadan that year. I address this concern by aggregating production to the district-year level in Table II, where overlap is defined as the weighted sum of overlap between Ramadan and each of the 18 crops, with weights given by each crop's average share of production in all other years. The resulting estimates are statistically indistinguishable from those estimated at the crop level, indicating that substitution between crops is not driving the results.

A second potential margin is fallowing — leaving land unplanted rather than incurring the cost of reduced productivity. This can be tested directly using data on acreage planted for a given crop and the same triple-difference identification strategy. As shown in Table IV, the point estimates are negative but insignificant and economically small, ruling out changes of more than 2% in the land allocated to a given crop.

Other margins include substitution toward draft labor (bullocks) or fertilizer. There is no measurable change in the use of draft labor (Table IV, Column 2), though this null result should be interpreted with some caution: the data are aggregated to the district level, and

[7]The coefficient of variation is defined as the standard deviation divided by the mean. For example, a crop with production of 90 in year one, 100 in year two and 110 in year three would have a standard deviation of 10 and a mean of 100 resulting in a coefficient of variation of 10.

changes in draft labor use are more likely to occur on the intensive margin (e.g., additional hours of use) than the extensive margin (the number of bullocks available), which this data may not fully capture. There is a small increase in fertilizer use when Ramadan overlaps with the sowing period, but no corresponding change during harvest. Finally, it may also be possible to adjust labor inputs by hiring non-Muslim individuals during the holiday period. This possibility is explored and rejected in Section 5 below.

Taken together, I find little evidence that farmers adjust other agricultural inputs in response to Ramadan's overlap with the cropping cycle, beyond the modest increase in fertilizer use noted above. However, this may or may not reflect a lack of awareness among farmers. One interpretation of this evidence is that farmers may be inattentive to the declines in production given the large year to year variation in output and the difficulty in attributing the changes to one factor in a context in which many inputs (e.g. rain) change frequently (Hanna et al., 2014). Or, alternative strategies such as switching to less suitable crops, hiring draft labor, or fallowing land may simply be too costly. Further, tight seasonal labor markets may make continued hiring privately optimal even when the productivity cost of fasting is known.

5 Evidence Regarding the Forces Driving Production Declines

This section examines what behavioral changes may drive the observed declines in output during Ramadan. There are four major potential changes in behavior that could plausibly impact output in a significant manner: changes in labor supply due to religious or social obligations, declines in caloric intake, dehydration due to lack of consumption of water during the fast, or sleep deprivation due to rising early or going to bed late in order to observe the fast.

First, I directly examine possible changes in labor supply and earnings among Muslims during Ramadan using a differences-in-differences strategy on data from the National Sample Survey labor survey and the ICRISAT village level studies survey. Second, I utilize a similar identification strategy and data from the consumption module of the NSS to estimate changes in caloric intake among Muslims during Ramadan to shed light on the possibility that changes in nutrition impact production. Although direct data on a third possible channel, sleep deprivation, is limited, I explore evidence for these potential drivers of low productivity via relevant literature. Next, I augment the primary specification in the World Bank agricultural data with additional weather data to shed light on whether dehydration due to lack of fluid intake during the day while observing Ramadan drives production declines. An additional calibration exercise is also conducted using data from the literature to add evidence on this potential driver.

Finally, I conduct an omnibus test related to the timing of the changes in output. Specifically, while recovery from sleep deprivation and dehydration is rapid and any religious or social obligations associated with Ramadan should cease at the end of the holiday, caloric changes have longer term impacts on productive capacity (Belenky et al., 2003; Dinges et al., 1997; Sawka et al., 2007; Keys et al., 1950). Hence, if overlap between the period following Ramadan (leaving a gap for Eid, a holiday at the conclusion of Ramadan) and sowing or harvest period is associated with declines in production, it would provide evidence supporting the role of caloric decline in reduced production during Ramadan.

Although it is difficult to fully parse these potential channels in a natural experiment and more than one channel may contribute, collectively these tests provide suggestive evidence that changes in caloric intake may be an important driver of the observed output changes.

5.1 Time Spent on Religious and Social Activities

Relevant Literature. Time spent on religious and social activities during the Ramadan holiday is likely to vary substantially across both individuals and locations, and little information specific to India is available given the relatively low concentration of Muslims there. However, the literature does provide general information about the types of behavioral changes that Muslim individuals are likely to engage in during the holiday. The primary religious behavioral changes expected during Ramadan are an increase in the number of prayers offered, abstinence from smoking, sexual relations, and swearing during the day, and an increase in charity. While a general guideline to increase prayers and reading and recitation of the Koran exists, no specific rules are provided regarding the amount or timing of the prayer that should be completed beyond the standard prayers observed throughout the year, five times daily. Similarly, there are no specific guidelines for the amount of charity to be provided during this time.

In addition to these changes in religious practice, Muslims often spend time in social gatherings in the evenings during Ramadan. The most common set of activities following sunset is to break the fast with a small snack, to complete the fourth set of daily prayers, and then to gather with friends or family for a large evening meal (Blackwell, 2009; Ahmad et al., 2012). So, although there is an increase in religious and social activity during this time, much of the increase occurs in the evenings when individuals would not typically be working.

In addition, because the prescribed changes in behavior are general and flexible, they are less likely to interfere with work requirements than observance of many other holidays. Finally, although some heavily Muslim counties see shifts in working hours during Ramadan, the smaller proportion of Muslims in India make these types of labor market changes unlikely to occur in this context.

Empirical Evidence - No Change in Labor Supply or Earnings During Ramadan. To examine labor supply changes among Muslims in India during Ramadan, I draw on two sources of data: the second-generation ICRISAT village level studies survey – a more geographically limited and smaller but more detailed survey – and the National Sample Survey (NSS) – a large and nationally representative dataset with lumpier labor supply data (National Sample Survey Organization, 2019). In more detail, ICRISAT is a panel dataset containing monthly measures of employment and earnings. The sample was drawn from six villages chosen to be representative of the major agro-climatic zones in the semi-arid tropics of India. Households were sampled across four categories of landholdings (landless, small farmers, medium farmers, and large farmers). The National Sample Survey is a large, nationally representative, repeated cross-sectional survey containing data on employment and consumption. The employment/unemployment rounds (Schedule 10) provide information on respondents' labor supply and wages during the seven days preceding the interview as well as their religious affiliation. Households were sampled on a rolling basis such that the sample is temporally spaced within each district.

Empirical Strategy and Results. In the ICRISAT data, labor supply (or earnings) of individual i, in survey round s, and year-month t are regressed on the number of days of overlap between survey period and Ramadan (R_{ist}), an interaction between that variable and an indicator for whether the individual is Muslim (M_i), a variable for the number of days between interviews (D_{ist}) to account for survey variation, and fixed effects for individuals (λ_i) and the year-month in which the survey occurred (ψ_t) (Equation 3). "Labor days" is defined as the number of days of labor, including both paid and unpaid labor but excluding domestic work, in the past month. The wages variable is calculated as the sum of cash and in-kind wages during the month. The number of hours worked is only reported for paid labor. If the participant reports more than one paid job during the survey period, the average hours worked per day is calculated as a weighted average across all jobs reported.

$$l_{ist} = \beta_0 + \beta_1 R_{ist} + \beta_2 R_{ist} * M_i + \beta_3 D_{ist} + \lambda_i + \psi_t + \varepsilon_{ist}. \tag{3}$$

A similar specification is used with the NSS data, with adjustments to account for the fact that the data consists of multiple cross sections rather than a panel. As can be seen in Equation 4, labor supply (or earnings) of individual i, in district d, at time t (l_{idt}) is regressed on the days of overlap between the survey period and Ramadan (R_{idt}), whether the individual is Muslim (M_{idt}), the interaction of these two variables ($R_{idt} * M_{idt}$), district-year fixed effects (λ_{dt}), and month of survey fixed effects (ψ_m) to account for seasonal variation in labor supply. "Labor days" is the combination of days engaged in labor for wages and own-labor (e.g. working on one's own farm) excluding domestic work. Wages are the total (cash plus in-kind) wages received during the survey period. Earnings are considered in both levels and logs to account for unemployment and unpaid labor.

$$l_{idt} = \beta_0 + \beta_1 R_{idt} + \beta_2 M_{idt} + \beta_3 R_{idt} * M_{idt} + \lambda_{dt} + \psi_m + \varepsilon_{ist}. \tag{4}$$

Table V provides the results of these regressions. In both datasets, Muslims' labor supply and earnings during the holiday are fairly precisely estimated (a change in labor supply of less than 2% per day of overlap can be detected). Perhaps surprisingly, both earnings and labor supply remain unchanged or increase very slightly for Muslims during Ramadan. The point estimate on labor supply in the NSS is a precisely estimated zero. However, it is possible that the lumpy reporting of labor supply (at the half day level with a large fraction of individuals reporting working seven days per week) makes detecting more minor adjustments such as leaving early difficult. In the ICRISAT data, the point estimate on labor supply on the extensive margin (days worked) is small – less than 1% – but positive and marginally significant while there is no detectable effect on hours worked per day in that data. The estimated change in earnings among Muslims during Ramadan is a precisely estimated zero in the ICRISAT data and an increase of approximately 1% in the NSS data, though the increase is only marginally statistically significant in logs (and not statistically significant in levels).

Possible explanations for the observed slight increase is labor supply are either an attempt to compensate for reduced productivity and/or to accrue funds for charity, which Muslims are expected to provide during Ramadan. Regardless of the cause, these results suggest that changes in labor supply driven by religious or social obligations are unlikely to drive the observed declines in production when Ramadan overlaps with important parts of the agricultural cycle and may (weakly) work against such declines.

5.2 Nutrition

Caloric Intake and Body Mass Index in India. The Indian Planning Commission's recommended caloric intake has typically been 2,100 calories per adult in urban areas and 2,400 calories per adult in rural areas (Sharma, 1999). Caloric intake in India has, however, remained significantly below these levels for many years and, of note, has been declining over time despite strong economic growth (Deaton and Drèze, 2009). In addition, the distribution of calories in India is quite skewed, such that mean caloric intakes are substantially higher than median caloric intakes. The low caloric intakes lead to correspondingly low body mass indices (BMI), with over half of the population below the WHO cutoff for underweight (BMI < 18.5) in 1971, the median year in this study. Roughly one-third of the population remains underweight at present (Deaton and Drèze, 2009; World Health Organization, 2013).

Although Muslims fast during daylight hours during Ramadan, it is possible that there could be substitution of food consumption across time to the evenings and mornings, limiting or eliminating declines in caloric intake. Hence, I directly estimate the change in caloric intake in order to shed light on the plausibility of this channel.

Data. This analysis utilizes the consumer expenditure portion of the 60th, 62nd, and 64th rounds of India's National Sample Survey (NSS, Schedule 1). The dataset provides retrospective data on household level consumption data for nearly 150 food items over the past month or the past week. These rounds cover a period substantially later than that covered by the agricultural data. Although use of earlier rounds would be ideal, it is not possible as only the more recent rounds include precise survey dates that are required to calculate overlap between the survey period and Ramadan. Per capita caloric intake is calculated for the 36,000 households living in rural areas and engaged in agricultural labor. The conversion from the quantity of food consumed to caloric content is completed using the conversion tables provided by the NSS.

Results - Changes in Caloric Intake. I estimate caloric declines among Muslim households during Ramadan according to the following equation:

$$C_{idt} = \beta_0 + \beta_{1r} R_i + \beta_2 F_{it} + \beta_{3r} R_i * F_{it} + \beta_4 E_{it} + \beta_{5r} R_i * E_{it} + \gamma_{dt} + \psi_m + \varepsilon_{ist}. \quad (5)$$

C_{idt} is calories per capita per day in household i, in district d, in year t. R_i is a vector of binary variables for the household's religion. F_{it} is an indicator variable denoting full overlap of the survey period and Ramadan. E_{it} is an indicator for overlap between the survey period and Eid, and γ_{dt} and ψ_m are district-year and month of survey fixed effects, respectively. The sample is limited to rural households whose primary occupation is agricultural work and which have either no overlap or complete (29 day) overlap between the survey period and Ramadan for ease of interpretation.

Although imprecisely estimated, the results suggest a fairly substantial decline in caloric intake among rural Muslim households during Ramadan (See Table VI). The decline appears to be approximately 600 calories per person per day, an estimate consistent with not eating a midday meal. Notably, neither protein nor fat consumption changes significantly during this time suggesting that the dietary mix does become slightly "richer", despite the decline in calories.[8] This decline is substantial relative to total caloric consumption, which is approximately 2200 calories per capita per day despite the fact that most individuals in this population engage in heavy physical labor. The results are robust to and strengthened by a variety of methods of topcoding used to address implausibly high consumption levels. Although imprecise enough that the evidence is not definitive, these results are consistent with previous literature suggesting that calories have the potential to influence productivity (see Section B.1) and further suggest that reduced caloric intake has the potential to play a role in the decrease in agricultural production during Ramadan. These results are explored further via the omnibus test in Section 5.5.

5.3 Sleep

No direct evidence on the level of sleep experienced by the rural Indian population during this period exists. Hence, no direct tests of this relationship can be conducted in this precise context. However, below I provide evidence on the plausibility of this relationship by drawing on the relevant literature regarding sleep's impact on physical and cognitive performance. In addition, the omnibus test examining overlap between the period following Ramadan and the sowing and harvesting seasons, which is described in greater detail below, also sheds indirect light on whether sleep is likely to play a substantial role in the observed production declines.

Literature - The Impact of Sleep on Cognitive and Physical Function. A limited literature on the impact of Ramadan on sleep habits does exist. However, it focuses

[8] Results available upon request.

on countries such as Saudi Arabia which are nearly exclusively Muslim (Bahammam (2006) provides a review). Because the holiday is celebrated so widely in these countries, the habits of the country as a whole often shift during the month of Ramadan. For example, stores often both open and close later than usual. However, because the median district in this study is only 7% Muslim, these equilibrium shifts are unlikely to occur in India. In addition, within this literature, changes in sleep patterns appear to vary widely across countries (Bahammam, 2006). Hence, the direct literature on changes in sleep patterns during Ramadan is unlikely to aid in understanding the likely impact of possible changes in sleep patterns on agricultural production in India. Instead, I focus on the more extensive and relevant literature surrounding the physiological relationship between chronic partial sleep deprivation, defined as 2 to 7 hours of sleep per night for periods of days to months, and physical and cognitive performance to understand the likely effect of changes in sleep patterns during the holiday.

The effects of sleep deprivation on performance appear to be heavily cognitive and occur primarily when sleep drops below six to seven hours per night (Goel et al., 2009; Durmer, 2005). When sleep drops below this level, the largest and most consistent effects center on changes in mood with increased sleepiness and negative affect (Alhola and Polo-Kantola, 2007; Durmer, 2005). In addition, in sleep labs and high-income countries chronic sleep deprivation of less than 6 hours per night is likely to lead to reduced vigilance, poorer memory consolidation, and slowed reaction time and learning (Blagrove et al., 1995; Rogers, 2003; Ferrara and De Gennaro, 2001; Van Dongen et al., 2003). These effects on mood and cognitive function typically tend to have a relatively linear relationship with the cumulative deprivation in the early stages and then often level off over a longer time horizon (multiple weeks) as individuals acclimatize to the new regimen (Ferrara and De Gennaro, 2001).

Despite cognitive declines associated with less than six hours of sleep per night, the evidence to date suggests that reduced sleep has little impact on physical performance until the deprivation becomes relatively extreme (Guezennec et al., 1994; Sinnerton and Reilly, 1992; VanHelder and Radomski, 1989). Some studies do show declines in time to exhaustion after extended periods of sleep deprivation (Reilly and Piercy, 1994; VanHelder and Radomski, 1989; Vardar et al., 2007). However, results are mixed and the conditions of deprivation are much greater than those likely to be experienced during Ramadan.

Finally, a more recent randomized trial on sleep in India suggests that modest changes in nighttime sleep (30 minutes per night over the course of one month) have no impact on physical performance (measured by an index of performance on an exercise cycle and daily steps) or on cognitive function (as measured both via direct laboratory measures of cognitive function and performance in a data entry job) at the levels of sleep and sleep quality experienced in this population (Bessone et al., 2021).

In short, although direct evidence is limited, making it difficult to draw strong conclusions, the literature relating sleep to cognitive and physical outcomes suggests that changes in sleep patterns during Ramadan are unlikely to be a significant driver of changes in production in this context. Physical capabilities are quite resistant to decreased sleep, even when the physical requirements are substantial as in military combat training. And although extended sleep deprivation is clearly associated with declines in specific areas of cognitive function, the sleep deprivation in these studies tends to be both more extreme than is likely to be experienced during Ramadan and its impact tends to be limited to specific domains of cognitive function (e.g. memory, reaction time) that are unlikely to be strongly related to agricultural production. Finally, the most relevant evidence — drawn from an RCT in India with an increase in sleep of 30 minutes per night over one month — suggests that modest changes in night sleep do not impact overall physical performance.

5.4 Dehydration

In addition to fasting, observant Muslims also refrain from drinking water during daylight hours during Ramadan. This restriction may cause individuals to become dehydrated, especially those individuals engaged in hard labor in hot climates. To examine whether dehydration may be a driver of the observed declines in output during this period, I draw on three sources of evidence: 1) a review of relevant literature, 2) an empirical test examining the impact of weather conditions which increase the rate of perspiration on output (controlling for the impact of those conditions on plant growth), and 3) the omnibus test conducted below which examines declines in production associated with overlap between sowing/harvesting and the period following Ramadan. Because recovery from dehydration is rapid, dehydration is unlikely to drive longer term impacts on production following the Ramadan holiday.

Literature - The Impact of Dehydration on Cognitive and Physical Function. The human body is remarkably efficient at regulating hydration via changes in plasma osmolarity (water-electrolyte balance) which drives re-absorption as needed (Jéquier and Constant, 2010). However, with extended exercise and lack of fluid replacement, dehydration does begin to negatively impact measures of aerobic performance once 2% of body weight has been lost. These declines become more consistent around 3 to 4% loss in body weight; however, even at these levels results are mixed (Casa et al., 2005; Sawka et al., 2007). There is generally no detectable impact of dehydration on strength and anaerobic performance until at least 5% of body weight is lost from water loss (Casa, 1999a,b; Greiwe et al., 1998; Sawka et al., 2007). There is also more limited evidence that dehydration beyond 2% of body weight may cause declines in cognitive function in areas such as short term memory consolidation (Grandjean and Grandjean, 2007).

Given that these findings suggest that dehydration's likely impact depends on its extent, it is necessary to estimate the expected body weight losses due to dehydration for fasting farmers in India. While, to the best of my knowledge, no direct evidence on body water loss rates among farmers in India exists, it is possible to benchmark expected losses relative to sports activities in which sweat rates have been measured based on caloric requirements and environmental factors.[9] This calibration, outlined in Section B.5, finds that expected water losses by the end of the day are around the 2% threshold at which aerobic effects become detectable. Given that these losses are cumulative throughout the day, and the mean losses at the day's end just reach the threshold for detectable impacts on physical performance, it is likely that most farmers are not significantly impacted by dehydration during this time. However, as some individuals are likely to reach this threshold, I conduct an additional test to shed further light on the magnitude of such potential effects.

Empirical Evidence – No Decrease in Production with Higher Perspiration Rates. In order to provide additional evidence on this potential pathway, I utilize the fact that atmospheric conditions can significantly impact the rate of perspiration and water loss. Specifically, evaporative potential (PET) is a measure of the propensity of water to evaporate into the atmosphere.[10] If dehydration were a significant factor in production, then as evaporative potential increased body water loss would also increase, and production would decline. However, evaporative potential is also likely to influence agricultural production directly. Hence, this test augments the previous specification not only with a main effect for the average PET over the sowing and harvesting seasons to account for direct effects on output, but also with interactions between high PET (HPET) during the relevant season – defined as districts in the top quartile of PET measurements for that season – and overlap

[9]Although no direct evidence on the extent of dehydration during fasting in India is available, related research does exist. The closest existing study examined 10 female farmers in Ghana working while fasting in similarly challenging environmental conditions – 7 to 8 hours of labor per day in temperatures exceeding 30 degrees Celsius in the shade with over 80% relative humidity. These women lost an average of 3.8% of their body weight by the time they broke their fast in the evening (Prentice et al., 1984).

[10]Data on PET were obtained from the British Atmospheric Data Center (BADC) and Climatic Research Unit (CRU) Databases.

between the seasons and Ramadan (Equation 6).

$$q_{cdt} = \beta_0 + \beta_1 S_{cdt} + \beta_2 H_{cdt} + \beta_3 HPET^S_{cdt} + \beta_4 HPET^H_{cdt} + \beta_5 S_{cdt} * HPET^S_{cdt} + \beta_6 H_{cdt} * HPET^H_{cdt} + \theta_{cd} + \gamma_{dt} + \alpha_{ct} + \kappa_c + \zeta_d + \tau_t + \beta_n X_{cdt} + \varepsilon_{ctd}. \tag{6}$$

The results of these regressions do not suggest a significant role for dehydration in driving production declines (Table VII). If dehydration were reducing output, the interactions between high evaporative potential and sowing or harvesting would be negative. However, the coefficients are mixed – with different signs between sowing and harvesting seasons – and none are significant. Further, the addition of these terms does not eliminate the negative effect of overlap between sowing/harvesting and Ramadan observed in the earlier regressions as would be expected if dehydration were the key factor in production declines. Rather, these terms remain negative and significant.

5.5 Omnibus Test - Persistence of Production Declines Following Ramadan.

A distinctive feature of low caloric intake is that recovery from this state takes time, often requiring weeks or even months to fully regain physical performance in extreme cases of deprivation (e.g., Keys et al. (1950)). This lag between increased caloric intake and improved physical performance suggests that the reduced caloric intake during the holiday would be expected to have an impact beyond Ramadan itself.

In contrast, recovery from sleep deficits and dehydration is rapid. And as discussed in greater detail above, sleep deficits primarily influence cognitive rather than physical function. However, a number of researchers have documented that a single night of greater than eight hours of sleep reverses cognitive deficits from extended (24-48 hours) periods of total sleep deprivation (Drummond et al., 2006; Kendall et al., 2006; Brendel et al., 1990). Similarly, Belenky et al. (2003) cannot distinguish measures of attention and reaction time between groups which had either five, seven, or nine hours of sleep per night for one week after a three-day recovery period with eight hours of sleep per night. Dinges et al. (1997) also demonstrate that two nights of ten hours of sleep is sufficient to overcome deficits accumulated over seven nights with five or fewer hours of sleep. Similarly, for recovery from dehydration, Sawka et al. (2007) survey a variety of sources and note that normal body water and performance can typically be restored within 8 to 24 hours even after fairly extensive dehydration.

These rapid recovery periods from sleep deprivation and dehydration suggest that if reduced production during Ramadan were due to sleep deprivation, dehydration, or changes in labor supply related to religious obligations that these deficits should disappear within a few days after the conclusion of the holiday. In contrast, if the reduced production is the result of lower caloric intake during the month, there should continue to be residual effects which reduce production in the weeks following the holiday. Hence, examining the impact of overlap between the sowing and harvesting seasons and the weeks following Eid (a short holiday immediately following Ramadan) serves as a useful test to distinguish between nutritional deficits and other behavioral changes during the holiday as likely causes of the reduced production.

This test is conducted using an empirical approach similar to the previous analyses, in which the fraction of Ramadan covered by the sowing and harvesting seasons is replaced with the fraction of the weeks following the holiday covered by the sowing and harvesting seasons. However, because the Eid holiday could potentially confound the results and there is a short recovery period for dehydration and sleep deprivation, I calculate overlap with the first and second week following Eid rather than following Ramadan. The estimating equation, Equation 7, is displayed below. P_{cdt}^{XN} denotes the overlap between season X (where $X = \{S \text{ for sowing}, H \text{ for harvesting}\}$) and week N (where $N = \{1, 2\}$). All other variables are as defined previously.

$$q_{cdt} = \beta_0 + \beta_{XN} P_{cdt}^{XN} + \theta_{cd} + \gamma_{dt} + \alpha_{ct} + \kappa_c + \zeta_d + \tau_t + \beta_n X_{cdt} + \varepsilon_{ctd}. \tag{7}$$

Although the standard errors are larger and the point estimates slightly smaller on average, the results of overlap for the first week post-Eid are quite similar to the results during the holiday itself for both sowing and harvest (Table VIII). This effect is robust to longer (4 day) specifications for Eid (Columns (3) and (4)). While the point estimates remain similar for the second week post-Eid for sowing, the effects attenuate by the second week following Eid for harvest, as might be expected given the relatively brief period of deprivation.

In short, while not conclusive, these results are consistent with the loss in productivity being driven by reduced caloric intake but inconsistent with diminished productivity being driven by dehydration, sleep deficits, or time spent on religious activities. This omnibus test is also consistent with the tests presented previously which show: (i) no significant change in labor supply during the holiday, (ii) and no increase in the extent of declines as individuals become increasingly dehydrated, and (iii) the decline in caloric intake during this period among Muslim households. Hence, while fully isolating the channels through which these effects operate is not likely to be possible, there is strong suggestive evidence that nutrition is likely to be a key channel in this context.

6 Conclusion

Religious practice is widespread and disproportionately prevalent among the world's poor. This practice offers many benefits that are challenging to quantify — a sense of purpose, belonging, and connection to others — but, may also come with economic costs that have been challenging to measure cleanly, particularly at a micro level. This study begins to close that gap by utilizing a natural experiment to provide a well-identified estimate of the contemporaneous economic cost of a common religious practice. The analysis takes place in the agricultural sector of India, a sector central to the livelihoods of the rural poor (in India and elsewhere) and accounting for half of all employment in the period studied. Because Muslim's are a small minority in rural India during this period, this variation offers a window into the cost of individuals' observation of the holiday, absent larger societal shifts that are likely to occur in more religiously homogeneous environments. This setting with more granular data also allows me to provide suggestive evidence on the channels through which the cost of Ramadan observance operates in lower-income settings.

I find declines in total agricultural production between 2.0 and 2.9% in quantity and 3.4 and 4.7% in value when Ramadan and labor-intensive parts of the agricultural cycle fully coincide, or an average decrease of approximately 1% of India's agricultural GDP (0.5% in overall GDP) annually during this period. Reassuringly for the identification strategy, there are no declines in production in districts with few Muslims, but large declines in districts with many Muslims. Although the overall declines are relatively small in percentage terms, they are economically meaningful and correspond to much greater declines in productivity — roughly 20 to 40% per Muslim individual — given the low fraction of Muslims in the rural population during this period.

Despite these meaningful changes in output, I do not observe any major changes in agricultural production processes or inputs such as fertilizer, draft labor, or land in reaction to Ramadan. This lack of adjustment may or may not reflect a lack of awareness: Muslim agricultural labor is typically dispersed across many employers, so the shock to any single farm may be small, and if seasonal labor markets are tight, continuing to hire available workers at reduced productivity may be privately optimal even when farmers are aware of the decline.

Liquidity constraints and missing markets could limit adjustment further. Understanding whether adjustments are particularly difficult among the poor, who are more likely to face missing markets or liquidity constraints that prevent adaptation to such costs, would improve our understanding of the distribution of the costs associated with various religious practices.

The final portion of the paper analyses four potential channels through which Ramadan may influence output: reduced labor supply, reduced caloric intake, sleep deprivation, and dehydration. Although fully parsing these channels is difficult in a natural experiment, the available evidence is suggestive of caloric decline as a meaningful driver and is not consistent with large productivity declines through the other channels explored. Well-identified field evidence on the relationship between caloric intake and productivity remains scarce, and these results, while not conclusive, contribute to that literature.

While this paper focuses on the impact of Ramadan because of its advantages in identification, practices from other religions are likely to have similar impacts. For example, fasting is a practice common to many religions including Hinduism, Christianity, and many other religions. Of course, the exact magnitudes of such effects are unlikely to be directly comparable across either religions or geographies within a religion. However, future research to improve our understanding of the range in the magnitude of these effects and the features of religious practices which generate such effects would broaden our understanding of religion's role in economic production.

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7 Tables and Figures

Table I: Effect of Overlap Between Ramadan and Cropping Cycles on Output

	All Crops		Rice Only	
	(1) ln(quantity)	(2) ln(value)	(3) ln(quantity)	(4) ln(value)
Overlap sowing	-0.020*	-0.034***	-0.041**	-0.016
	(0.010)	(0.011)	(0.018)	(0.019)
Overlap harvest	-0.029***	-0.047***	-0.043***	-0.043**
	(0.009)	(0.009)	(0.016)	(0.017)
Observations	103104	103088	7741	7741
Mean of DV	1.517	1.837	3.910	3.998

Notes: This table tests for changes in agricultural output in each district-crop-year as a function of overlap between Ramadan and the sowing and harvesting season for that crop-district-year.

- Overlap is defined as the fraction of Ramadan covered by the sowing (harvesting) season such that multiplying coefficients by 100 produces the decline associated with complete overlap between Ramadan and the season. A more detailed description of calculation of the overlap variables is included in Section B.2.
- The dependent variables are: Columns (1) and (3), log production in thousands of tons, and Columns (2) and (4), log value of production (in 1,000,000 Rs deflated to 1973). Columns (1) and (2) include all 18 crops whereas Columns (3) and (4) are limited to rice only. Rice is both the most commonly consumed staple grain and the most economically important crop in India.
- Columns (1) and (2) include district-crop, district-year, crop-year, district, year, and crop fixed effects. Columns (3) and (4) include fixed effects for district and year. All regressions include time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two-month leads to each season, and a two-month lag following the sowing season.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table II: Effect of Overlap Between Ramadan and Cropping Cycles on Output, District-year Aggregation

	(1) ln(quantity)	(2) ln(value)
Overlap sowing	-0.060***	-0.035
	(0.020)	(0.022)
Overlap harvest	-0.039**	-0.066***
	(0.019)	(0.023)
Observations	8636	8636
Mean of DV	5.807	5.960

Notes: This table tests for changes in agricultural output in each district-year as a function of overlap between Ramadan and the sowing and harvesting seasons for that district-year.

- Overlap at the district-year level is defined as the weighted sum of the overlap between Ramadan and each of the 18 crops, where the weights are the average fraction of production that the crop accounts for in all years excluding the current year. A more detailed description of the calculation of the overlap variables for each crop is included in Section B.2.
- The dependent variables are log production in thousands of tons in Column (1) and log value of production (in 1,000,000 Rs deflated to 1973) in Column (2).
- Regressions include district and year fixed effects as well as a vector of time-varying controls for monthly rainfall and temperature during both the current and leading agricultural year (to account for long crop cycles).
- * p<0.1, ** p<0.05, *** p<0.01.

Table III: Heterogeneity in Production Declines by Fraction Muslim

	Median Split		**Quadratic**	
	(1)	(2)	(3)	(4)
	ln(quantity)	ln(value)	ln(quantity)	ln(value)
Overlap sowing	0.019	0.002	0.021	-0.003
	(0.014)	(0.014)	(0.014)	(0.014)
Overlap sowing*Above p50 Muslim	-0.076***	-0.070***		
	(0.017)	(0.017)		
Overlap harvest	-0.003	-0.016	0.007	-0.007
	(0.011)	(0.012)	(0.012)	(0.013)
Overlap harvest*Above p50 Muslim	-0.050***	-0.061***		
	(0.014)	(0.015)		
Overlap sowing* Fraction Muslim			-0.969***	-0.791***
			(0.173)	(0.178)
Overlap sowing* Fraction Muslim squared			2.471***	2.196***
			(0.416)	(0.427)
Overlap harvest* Fraction Muslim			-0.941***	-1.001***
			(0.175)	(0.181)
Overlap harvest* Fraction Muslim squared			2.692***	2.742***
			(0.400)	(0.428)
Observations	103104	103088	103104	103088
Mean of DV	1.517	1.837	1.517	1.837

Notes: This table tests for changes in agricultural production in each district-crop-year as a function of the fraction of Ramadan covered by the sowing (harvesting) season and the interaction of that variable with various indicators for the fraction of Muslims in the district.

- Columns (1) and (2) interact the overlap variable with an indicator for an above median fraction of Muslims in the district. Columns (3) and (4) interact the overlap variable with a continuous variable for the fraction Muslim as well as this variable squared.
- Quantities (Cols. (1) and (3)) are in log thousands of tons and values (Cols. (2) and (4)) are in log 1,000,000 Rs deflated to 1973.
- The net decline in production and in productivity per Muslim individual at each fraction Muslim based in the estimates in Columns (3) and (4) are plotted in Figure IV.
- Regressions include district-crop, district-year, crop-year, crop, year, and district fixed effects as well as time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table IV: Potential Margins of Adjustment

	(1) Area	(2) Bullocks	(3) ln(fertilizer)
Overlap sowing	-0.110	3366.856	0.070***
	(0.195)	(2179.638)	(0.026)
Overlap harvest	-0.018	1839.502	-0.049
	(0.169)	(2244.222)	(0.031)
Observations	136960	8640	8434
Mean of DV	28.657	216713.335	7.932

Notes: This table reports on potential adjustments to agricultural inputs in response to overlap between Ramadan and the sowing or harvesting season.

- Area is measured at the level of the crop-district-year while draft animal labor (bullocks) and fertilizer use are captured at the level of the district-year. Hence, Column (1) utilizes the same estimation strategy and controls as the regressions in Table I while Columns (2) and (3) utilize the estimation strategy and controls in Table II.
- Area planted is measured in 10,000HA. Bullocks measures the number of castrated (male) cattle over the age of 3 years which are used in rural areas for work only. Fertilizer captures the natural logarithm of the sum of all fertilizers measured (nitrogen, phosphorus and potassium) in the dataset.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table V: Labor Market Outcomes During Ramadan

	ICRISAT Agricultural Laborers			NSS Agricultural Laborers		
	(1)	(2)	(3)	(4)	(5)	(6)
	Labor days	Average work hours	ln(total earnings)	Labor days	Total earnings	ln(total earnings)
Muslim*Overlap	0.155*	-0.003	0.002	-0.013	2.986	0.011*
Ramadan	(0.089)	(0.011)	(0.006)	(0.010)	(2.083)	(0.006)
Muslim				0.058**	51.685***	0.184***
				(0.024)	(6.859)	(0.024)
Overlap Ramadan	-0.039	-0.002	-0.004***	0.003	-0.171	-0.001
	(0.035)	(0.001)	(0.001)	(0.004)	(0.535)	(0.003)
Observations	31432	19417	19287	395505	395510	123007
Individuals	1146	910	914	395505	395510	123007
Mean of DV	21.752	7.131	6.816	6.007	135.623	5.727

Notes: This table provides a test of whether reduced labor supply by Muslims reduced agricultural production during Ramadan. Given the coarse nature of the labor supply variable in the NSS, the table also examines wages.

- Data in Columns (1)-(3) includes ICRISAT respondents for whom agricultural work is their primary occupation.
- The ICRISAT survey elicits information on labor supply, hours, and wages of the respondent during the preceding month. The number of days of overlap between Ramadan and the survey period is calculated as the number of days of Ramadan falling within the 30 days preceding the survey date. Labor supply is defined as the number of days paid and unpaid labor excluding domestic work in the past month. Wages include both cash and in-kind payments. Average hours worked is only reported for paid labor. If the participant reports more than one paid job, average hours worked is calculated as a weighted average across jobs. Religion is captured via the caste variable, which contains a category for Muslim individuals, because it is not directly reported.
- Regressions in Columns (1)-(3) include individual fixed effects, a control for the number of days between surveys, and year-month of interview fixed effects. Robust standard errors clustered by individual are in brackets.
- Columns (4)-(6) utilize data from the Indian National Sample Survey (NSS), Schedule 10 (Employment), rounds 60, 61, 62, 64, and 66. These rounds are selected because they contain survey dates while earlier rounds do not. The sample includes individuals for whom agricultural work is their primary or secondary occupation.
- The NSS Schedule 10 provides data on labor supply (to the half day) and wages during the preceding week. Labor supply is calculated as the number of days of labor excluding domestic work in the past week.
- Columns (4)-(6) include district-year and calendar month fixed effect. Robust standard errors clustered by district-year are in brackets.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table VI: Daily Calories per Capita in Rural Agricultural Households

	Primary	**Robustness**			
	(1) No topcoding	(2) P99 to mean	(3) P99 to P99	(4) P99 to mean, cond. on pos.	(5) P1 and P99, cond. on pos.
Muslim*Full overlap	-612.598	-601.279*	-620.198*	-880.169**	-725.513**
	(384.806)	(340.301)	(336.879)	(400.575)	(368.854)
Muslim	-107.497***	-96.837***	-89.493***	-106.743***	-92.462***
	(41.543)	(28.134)	(27.486)	(28.881)	(28.859)
Full overlap	455.086*	279.832	395.840	405.555	427.228
	(259.091)	(274.727)	(274.719)	(302.973)	(271.533)
Observations	36618	36618	36618	36618	36618
Mean of DV	2262.406	2019.813	2135.572	2143.297	2198.235

Notes: This table tests for changes in caloric consumption during Ramadan in Muslim households.

- The sample is drawn from the Indian National Sample Survey, Schedule 1 (consumption), rounds 60, 62, and 64 and is limited to households with survey periods with no overlap or full (29 day) overlap between the survey period and Ramadan. These rounds are included because they contain survey dates while earlier rounds do not.
- All regressions include district-year fixed effects and month of interview fixed effects. In addition, indicator variables for other major religions and their interaction terms with overlap between the survey period and Ramadan as well as overlap between the survey period and Eid (to address the fact that food purchases are lumpy and made in advance) and the interaction between this variable and the religion indicators are included in the regressions but omitted from the table for simplicity.
- The dependent variables are per capita daily caloric intake with six different methods of topcoding. Given concerns around units, all topcoding is done by food item before aggregating across the food items. The dependent variable is per capita daily caloric availability. Column (1) makes no adjustments to reported values. Columns (2) and (3) windsorize at the 99th percentile to the mean, and 99th percentile, respectively. Columns (4) and (5) are similar to (2) and (3), but use means and 99th percentiles conditional on households that have positive consumption of the good.
- NSS sampling weights are used and are reweighted to weight each round of the survey equally.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table VII: Test of Dehydration Driving Production Declines

	(1) ln(quantity)	(2) ln(value)
Overlap sowing	-0.065**	-0.062*
	(0.031)	(0.032)
High sowing PET	-0.001	0.010
	(0.029)	(0.029)
Overlap sowing*High sowing PET	0.047	0.050
	(0.066)	(0.067)
Overlap harvest	-0.072**	-0.075**
	(0.029)	(0.029)
High harvest PET	0.016	0.019
	(0.036)	(0.036)
Overlap harvest*High harvest PET	-0.052	-0.057
	(0.047)	(0.048)
Observations	11356	11356
Mean of DV	1.601	1.877

Notes: This table provides a test of whether declines in production during Ramadan are due to dehydration by examining changes in agricultural production in each district-crop-year as a function of overlap between Ramadan and sowing (or harvesting) seasons fully interacted with a measure of weather features which impact dehydration (evaporative potential or PET).

- PET is a measure of the propensity of water to evaporate. It is calculated based on temperature, vapor pressure, and cloud cover as recommended by the Food and Agricultural Organization (FAO). PET measures are not available for all districts in all years, resulting in a lower sample size.
- Regressions include district-crop, district-year, crop-year, district, year, and crop fixed effects as well as time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

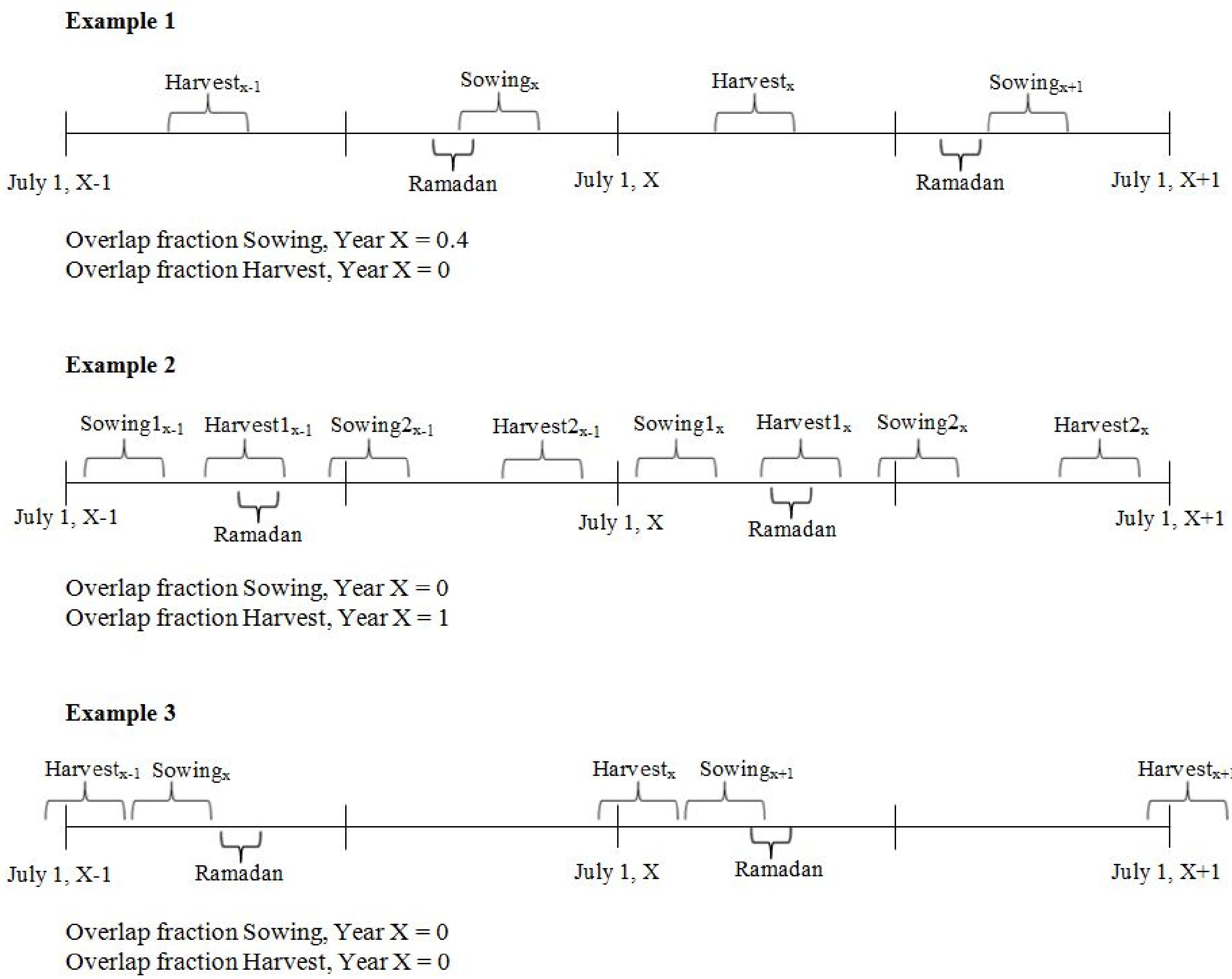
Table VIII: Persistence of Declines in Output Following Ramadan (and Eid)

	Short (2 day) Eid		Long (4 day) Eid	
	(1)	(2)	(3)	(4)
	ln(quantity)	ln(value)	ln(quantity)	ln(value)
Overlap sowing and 1st week post Eid	-0.016	-0.014	-0.022	-0.023
	(0.017)	(0.017)	(0.017)	(0.017)
Overlap sowing and 2nd week post Eid	-0.016	-0.018	-0.026	-0.025
	(0.017)	(0.017)	(0.018)	(0.017)
Overlap harvest and 1st week post Eid	-0.023	-0.004	-0.043***	-0.027**
	(0.014)	(0.013)	(0.014)	(0.014)
Overlap harvest and 2nd week post Eid	0.011	-0.006	0.024*	0.011
	(0.014)	(0.013)	(0.014)	(0.013)
Observations	103104	103104	103088	103088
Mean of DV	1.517	1.517	1.837	1.837

Notes: This table provides a test of whether declines in production during Ramadan are due to low caloric intake, which causes longer lasting decreases in productivity, or other potential factors including dehydration or sleep deprivation, from which recovery is rapid, or time spent on religious activities during the holiday. To accomplish this, this table examines changes in agricultural production (in log thousands of tons) in each district-crop-year as a function of the overlap between the first and second week following Eid (the holiday following Ramadan) and the sowing (harvesting) season for that crop-district-year.

- Eid is defined as a two day period in Columns (1) and (3) a four day period in Columns (2) and (4). These formulations are used because the holiday is lunar so the exact day of Eid will depend on the sighting of the crescent moon, which varies across locations. I build in a one day buffer to account for the uncertainty in sighting the moon. In addition, while the official holiday is only one day, some individuals continue to celebrate for up to three days. Hence, to span the possible durations of the holiday, I examine periods following both a two day and a four day lag for the Eid holiday.
- All regressions include district-crop, district-year, crop-year, district, crop, and year fixed effects. In addition, time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season are included.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

FIGURE I: Overlap Between Ramadan and Cropping Cycles, Calculation Examples



Notes: Agricultural years run from July 1 to June 30. A description of the overlap calculation procedure is provided in Section B.2.

FIGURE II: Rural Fraction Muslim Distribution

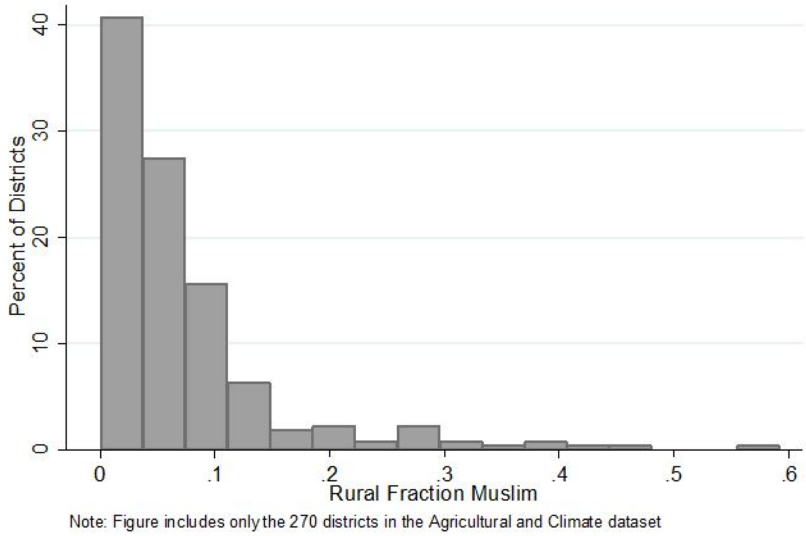
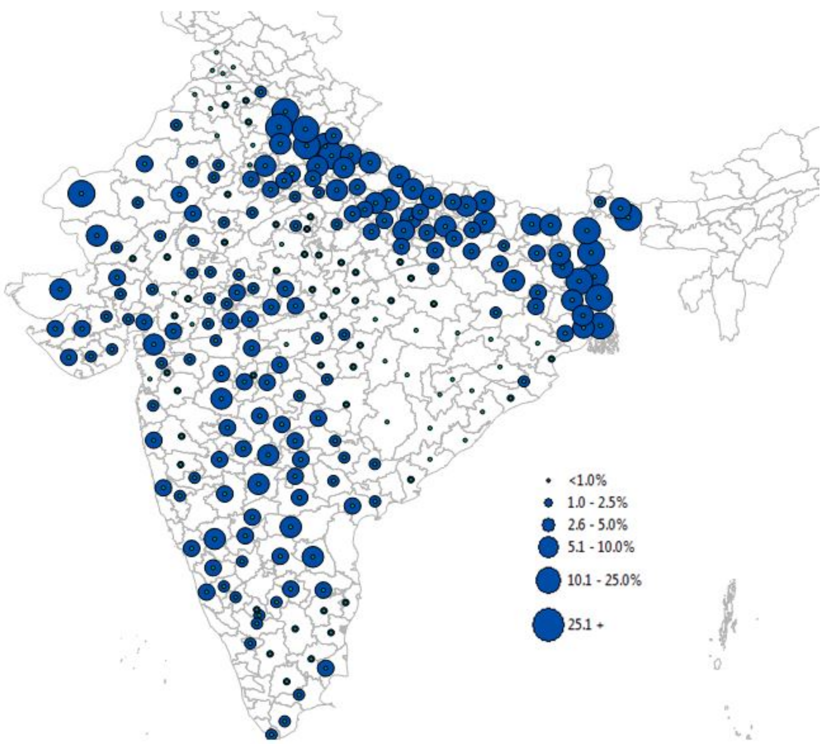
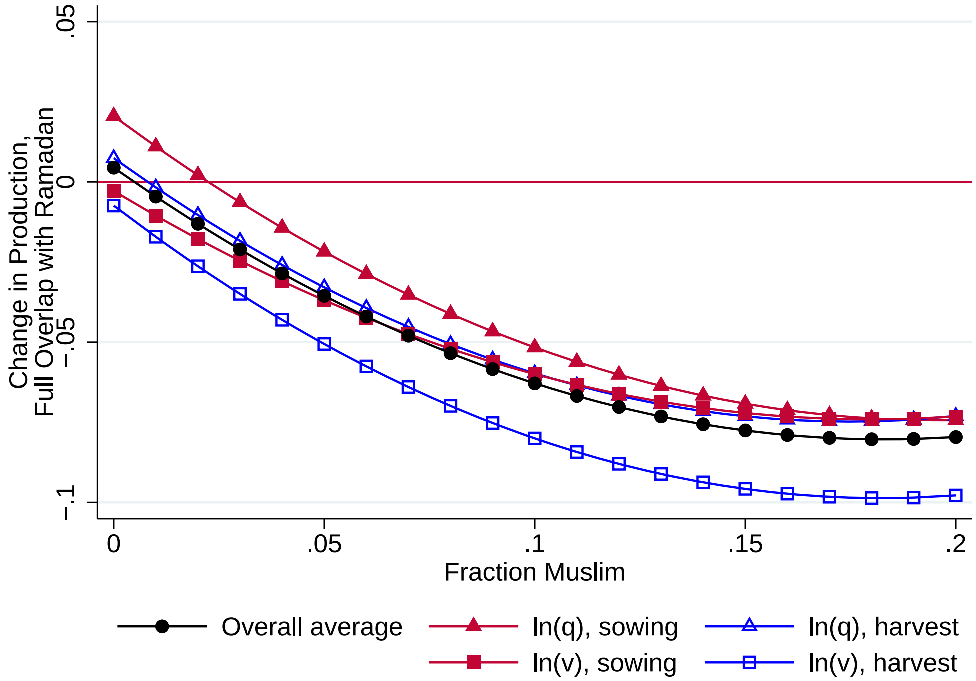


FIGURE III: Geographic Distribution of Muslims in India



Notes: Includes only the 270 districts included in the Indian Agriculture and Climate Dataset.

FIGURE IV: Production Declines by Fraction Muslim, Fitted Model



Notes: This figure plots the decline in agricultural production as a function of the fraction of Muslims in the district using a best fit quadratic function. The figure is truncated at 20% given that fewer than 10% of districts have greater than 10% Muslim population. Red (blue) lines capture predicted effects of overlap with the sowing (harvesting) season. Triangles and squares are used to differentiate quantities and values, respectively.

Appendix A Supplementary Tables and Figures

Table A.I: Overview of Data Sources

	Data set	Content	Analysis	Notes
(1)	Indian Agriculture and Climate Dataset (World Bank)	Annual agricultural production, prices, and inputs for 270 districts (85% of landarea) over 32 years for 20 crops	Output declines	Crop calendar information is available for 18 of the 20 crops
(2)	1967 Indian Crop Calendar	District specific sowing and harvesting seasons for 18 crops	Output declines	Compiled by Donaldson (2013)
(3)	University of Delaware Climate Resource Data	0.5 x 0.5 gridded monthly total rainfall and average temperature	Output declines	
(4)	Ramadan Dates	Start and end of Ramadan each year	All	Available online: http://www.timeanddate.com/holidays
(5)	Indian Census (1961)	The fraction of individuals of a given religion by district	Heterogeneity in output declines	
(6)	British Atmospheric Data Center (BADC) and Climatic Research Unit (CRU) Databases	0.5 x 0.5 gridding daily potential evapotranspiration (PET, a measure of evaporative potential) and maximum temperatures	Dehydration analysis	
(7)	National Sample Survey (NSS)	Consumer expenditures on food, labor supply	Labor supply and caloric intake analyses	Consumer Expenditure (Schedule 1, Rounds 60, 62, 64); Employment (Schedule 10, Rounds 43, 60, 61, 62, 64, and 66)
(8)	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Village Dynamics in South Asia Micro-level Data, Second generation	Labor supply	Labor supply analysis	

Notes: This table provides a brief overview of the data used in the paper.

Table A.II: Summary Statistics for Crops in the Agricultural Analysis

	(1) Mean quantity	(2) Mean value	(3) Percent of districts with positive production	(4) Sowing start, SD	(5) Sowing end, SD	(6) Harvest start, SD	(7) Harvest end, SD
Bajra (pearl millet)	19.21	17.00	84.30	24.26	35.34	28.47	30.76
Barley	12.36	10.93	90.63	15.27	19.26	18.83	17.57
Cotton	3.97	9.93	77.65	41.95	45.38	57.05	59.64
Groundnut (peanut)	21.33	39.70	98.82	32.54	38.20	31.64	35.49
Gram (lentils, chickpeas)	22.56	29.60	100.00	13.73	18.93	22.44	21.54
Jowar (sorghum)	39.58	35.67	92.15	50.28	57.05	52.80	54.62
Jute	5.84	9.86	64.71	60.58	49.09	50.49	43.00
Maize	17.86	15.03	99.26	31.46	33.32	34.96	33.70
Other pulses	8.15	12.03	78.89	41.56	48.28	45.57	53.12
Potato	21.06	11.70	86.67	62.43	62.22	58.49	58.56
Ragi (finger millet)	1.05	0.93	13.10	41.87	50.75	40.67	56.26
Rice	150.09	180.09	99.59	99.86	88.17	81.54	82.70
Rapeseed and Mustard (oils)	3.59	8.11	94.55	17.80	19.73	24.71	23.47
Sesamum (sesame)	1.35	3.79	99.16	50.95	54.10	46.92	52.71
Sugar	47.67	63.68	98.52	88.36	102.80	65.04	67.13
Tobacco	1.31	6.19	91.11	60.04	76.01	60.00	69.12
Tur (pigeon pea)	8.98	13.49	88.98	27.29	25.45	48.01	39.47
Wheat	107.72	108.72	99.05	10.57	16.05	19.95	21.34
Average	27.43	32.03	86.51	42.82	46.67	43.75	45.57

Notes: This table provides summary statistics for the crops used in this analysis.

- Production, Column (1), is in metric tons. Value, Column (2), is in 1,000,000 Rs deflated to 1973.
- Columns (4) through (7) provide the standard deviation of sowing and harvesting start and end dates to demonstrate the variation in the timing of cropping seasons.

Table A.IV: Distribution of Fraction of Ramadan Covered by Sowing and Harvesting Seasons

Percentile	Fraction of Ramadan covered by sowing	Fraction of Ramadan covered by harvest
50	0.00	0.00
75	0.00	0.03
90	0.86	0.93
95	1.00	1.00
99	1.00	1.00
Mean	0.16	0.17
N	103104	103104

Notes: This table provides distributional information for the primary independent variable of interest; the fraction of Ramadan covered by the labor-intensive portions of the cropping season, sowing and harvesting.

- The sample utilized for this table matches that of the primary specification listed in Table 9, Column (1).

Table A.III: Within District Variation in Cropping Cycles

	(1) Sowing start	(2) Sowing end	(3) Harvest start	(4) Harvest end
Average SD	74	72	74	76
Average Range	260	258	234	244

Notes: This table displays measures of the variation in the timing of cropping cycles for different crops within a district.

- The "Average Standard Deviation" is calculated as the standard deviation of the element of the cropping cycle listed at the top of the column within each district averaged across all districts. Similarly, the "Average Range" is the range in the timing of that element of the cropping cycle within a district, averaged across districts.
- Roughly 7% of crop-district combinations have more than one cropping cycle per year. All cycles are included in these figures (as well as all analyses).

Table A.V: Distribution of Muslims in Rural Areas

Percentile	Percent of the population that is Muslim
1	0.1
5	0.3
10	0.7
25	2.1
50	4.6
75	8.8
90	15.3
95	27.1
99	42.1
Mean (district weighted)	7.2
Mean (population weighted)	9.9

Notes: This table provides data on the fraction of the population that is Muslim in each district.

- Data in the table are drawn from the 1961 Indian Census and based on the 270 districts in the Indian Agricultural and Climate Dataset.
- The census disaggregates the district into rural and urban areas. Given that the analysis examines agricultural production, the data here are drawn from rural areas only.

Table A.VI: Effect of Overlap Between Ramadan and Cropping Cycles, Robustness

	No Weather Controls		**Levels**	
	(1)	(2)	(3)	(4)
	ln(quantity)	ln(value)	quantity	value
Overlap sowing	-0.023**	-0.036***	-2.512***	-1.715***
	(0.010)	(0.011)	(0.425)	(0.525)
Overlap harvest	-0.028***	-0.047***	-1.962***	-2.438***
	(0.009)	(0.009)	(0.414)	(0.504)
Observations	103104	103088	136960	136960
Mean of DV	1.517	1.837	27.459	32.156

Notes: This table tests for changes in agricultural output in each district-crop-year as a function of overlap between Ramadan and the sowing and harvesting seasons for that district-crop-year.

- The dependent variables are: log production in thousands of tons and log value of production (in 1,000,000 Rs deflated to 1973) in Columns (1) and (2), respectively. Levels of these variables are considered in Columns (3) and (4).
- Regressions include district-crop, district-year, crop-year, district, year, and crop fixed effects. In addition, time varying controls for average rainfall and temperature during the sowing and harvesting seasons, two month leads to each season, and a two month lag following the sowing season are included in Columns (3) and (4).
- Robust standard errors clustered by district-year are in brackets.
- * p<0.1, ** p<0.05, *** p<0.01.

Table A.VII: Robustness: Labor Supply and Earnings as a Test of Religious Obligations Driving Production Declines (NSS)

	Agricultural Laborers Full Year			**Agricultural Laborers High Labor Demand Seasons**			**Rural Casual Laborers Full Year**			**Rural Casual Laborers High Labor Demand Seasons**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Labor days	Total earnings	ln(total earnings)	Labor days	Total earnings	ln(total earnings)	Labor days	Total earnings	ln(total earnings)	Labor days	Total earnings	ln(total earnings)
Overlap*Muslim	-0.013	2.986	0.011*	-0.015	2.933	0.018**	0.017	1.797	0.005	0.005	3.178	0.013**
	(0.010)	(2.083)	(0.006)	(0.017)	(2.029)	(0.008)	(0.015)	(1.861)	(0.005)	(0.022)	(2.389)	(0.006)
Muslim	0.058**	51.685***	0.184***	0.099***	14.337***	0.072***	0.065	33.535***	0.140***	0.230***	20.324***	0.098***
	(0.024)	(6.859)	(0.024)	(0.034)	(4.655)	(0.017)	(0.047)	(6.139)	(0.016)	(0.054)	(7.139)	(0.019)
Overlap	0.003	-0.171	-0.001	0.001	0.282	0.001	-0.002	-1.468**	-0.001	-0.000	-0.677	0.001
	(0.004)	(0.535)	(0.003)	(0.008)	(0.767)	(0.004)	(0.009)	(0.731)	(0.002)	(0.013)	(1.166)	(0.004)
Observations	395505	395510	123007	130154	130156	50742	174386	174386	138478	67377	67377	55951
Mean of DV	6.007	135.623	5.727	5.931	142.412	5.610	4.863	306.767	5.727	4.962	289.329	5.633

Notes: This table provides a test of whether time spent on religious or social activities reduces production during Ramadan by decreasing the labor supply of Muslims during this time. Given the somewhat coarse nature of the labor supply variable, the table also examines wages.

- Samples are drawn from the Indian National Sample Survey, Schedule 10 (Employment), rounds 60, 61, 62, 64, and 66. These rounds are selected because they contain survey dates while earlier rounds do not. "Agricultural laborer" samples include only individuals who indicate that agricultural work is their primary or secondary occupation. The "Rural casual laborers" sample includes individuals living in rural areas who indicate that they participate in the casual labor market. "Full year" samples include the full survey periods. "High Labor Demand" additionally restricts the samples to surveys conducted during the sowing or harvesting seasons for the crop with the greatest acreage by state for the states included in the agricultural calendar.
- The NSS Schedule 10 provides data on labor supply (to the half day) and wages of the respondent during the week preceding the survey date. Labor supply is calculated as the number of days of labor excluding domestic work in the past week. The wages variable is calculated as the sum of cash and in-kind wages during the week.
- All regressions include district-year fixed effects and month fixed effects.
- Robust standard errors clustered by district-year are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Table A.VIII: Labor Supply and Earnings as a Test of Religious Obligations Driving Production Declines (Icrisat)

	Agricultural Laborers All Seasons			**Agricultural Laborers High Season**			**Full Sample All Seasons**		
	(1) Labor days	(2) Average work hours	(3) ln(total earnings)	(4) Labor days	(5) Average work hours	(6) ln(total earnings)	(7) Labor days	(8) Average work hours	(9) ln(total earnings)
Muslim*Overlap	0.155*	-0.003	0.002	0.142	-0.008	-0.007	0.180***	-0.001	0.002
	(0.089)	(0.011)	(0.006)	(0.142)	(0.019)	(0.008)	(0.068)	(0.006)	(0.003)
Overlap	-0.039	-0.002	-0.004***	-0.024	-0.002	-0.006***	-0.016	0.001	-0.002***
	(0.035)	(0.001)	(0.001)	(0.038)	(0.002)	(0.001)	(0.022)	(0.001)	(0.001)
Observations	31432	19417	19287	19481	12641	12520	72048	34267	33977
Mean of DV									
mean	21.752	7.131	6.816	21.874	7.212	6.778	17.921	7.182	7.014

Notes: This table provides a test of whether time spent on religious activities reduces production during Ramadan by decreasing the labor supply of Muslims during that period.

- Samples are drawn from the second generation ICRISAT village level studies survey. "Agricultural Laborers" samples include only individuals who indicate that agricultural work is their primary occupation. "Agricultural Laborers, High Season" samples include observations from individuals in the "Agricultural Laborers" sample for which the interview period had at least 15 days of overlap with a "high labor demand" period, defined as the sowing or harvesting seasons for the crop with the greatest acreage by state. The "Full" sample includes all individuals in the sample.
- ICRISAT surveys participants approximately once per month and elicits information on labor supply, hours, and wages of the respondent during the month preceding the survey date. The number of days of overlap between Ramadan and the survey period is calculated as the number of days of Ramadan falling within the 30 days preceding the survey date. Labor supply is defined as the number of days of labor including both paid and unpaid labor but excluding domestic work in the past month. The wages variable is calculated as the sum of cash and in-kind wages during the month. Average hours worked is only reported for paid labor. If the participant reports more than one paid job, average hours worked is calculated as a weighted average across jobs. Religion is captured via the caste variable, which contains a category for Muslim individuals, because it is not directly reported.
- All regressions include individual fixed effects, a control for the number of days between surveys, and year-month of interview fixed effects.
- Robust standard errors clustered by individual are in brackets.
- * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

Appendix B Additional Information for Reference

B.1 Literature – The Impact of Caloric Intake on Economic Productivity

There has been significant interest in the effect of caloric intake on productivity and labor market outcomes for many years. The earliest of these studies, relying on quasi-exogenous changes in caloric intake among men working at various tasks (e.g. coal mining, embankment construction) during war time, found that caloric availability was positively correlated with output (Kraut and Muller, 1946). Strauss (1986) improved on these correlational studies by utilizing a vector of food prices, farm assets, and household demographic characteristics to instrument for average caloric intake per adult equivalent to estimate a farm production function in Sierra Leone. The estimated production function showed a strong positive relationship between caloric consumption and farm production, with higher returns at lower levels of consumption. Yet, given the relatively high price of calories and the levels of caloric intake in Sierra Leone, the increased productivity did not account fully for the cost of the additional calories for the median individual. Using panel data from southern India to estimate both wage equations and farm production functions with individual fixed effects, Deolalikar (1988) found no significant impact of caloric intake on wages or farm output once stature (weight for height) was accounted for.

Three additional studies have also examined the impact of adult caloric supplementation on productivity through experimental methods in an effort to address the endogeneity of caloric consumption. Immink and Viteri (1981a,b) find no significant change in production when treated participants were provided with an additional 350 calories per day. However, due to logistical constraints, this experiment relied on two villages randomized at the level of the village. In addition, laborers in this study worked in groups of four and were paid one quarter of the group's total production, potentially weakening individual incentives. Wolgemuth et al. (1982) were able to randomize at the level of the individual and provided the treated individuals with an additional 800 calories per day relative to the control group. Because participants in this study were construction workers, productivity was estimated by visual inspection of the quantity of earth moved and required adjustments of productivity measures to account for differences in output across types of tasks.[11] Although production per day showed a small marginally significant increase in the intention to treat estimate, the number of days worked on the roads project declined significantly among treated individuals, making an overall assessment of economic productivity changes difficult. Finally, in more recent work Schofield (2018) supplements the caloric intake of cycle-rickshaw drivers in India by 700 calories per day for approximately one month. Relative to control workers

[11]The specific compensation method for workers is not explicitly stated in the paper. Wages are mentioned, however, the structure of the wages is not. Given that the labor provided was for a public works project, it is likely that there was simply a flat days wage for work on the project such that workers most likely faced relatively weak incentives.

who received the equivalent value in cash, the treated drivers increased labor supply and income by approximately 10% by the final week of the study.

B.2 Calculating the Overlap between Ramadan and Agricultural Seasons

Data in the India Agricultural and Climate dataset is organized by the agricultural year running from July 1 of year X to June 30 of year X+1. To calculate the overlap between the sowing and harvesting seasons and Ramadan, I first organize the crop calendar relative to the agricultural year such that an agricultural cycle for agricultural year X is defined by the seasons leading up to a harvest which occurs in agricultural year X.[12] This calendar is then overlaid with the Ramadan dates during the agricultural year of interest as well as the preceding year to account for extended agricultural cycles and harvests which occur early in the agricultural year. For example, the cropping cycle for sugar cane is typically between one and two years such that for a harvest occurring in agricultural year X, the sowing season typically occurs in year X-1. Similarly, if a harvest were to occur in July of agricultural year X, the sowing season would typically occur in year X-1. However, the overlap between these sowing seasons and the previous year's Ramadan would be assigned to the year in which the harvest occurred to coincide with the production data in the India Agricultural and Climate data.

In addition, because certain crops (e.g. rice, potatoes) frequently have more than one agricultural cycle per year, I calculate the days of overlap between each season (i.e. sowing, harvesting) and Ramadan for each cycle and then sum across the cycles ending in the same agricultural year. Finally, this total number of days of overlap is divided by 29, the number of days in Ramadan.[13] Figure I provides example overlap calculations and Table A3 provides the distribution of overlap between Ramadan and each of the agricultural seasons.

B.3 Calculating Rainfall and Average Temperature Controls

Although the Indian Agricultural and Climate dataset contains information on rainfall and temperature, the values are averages across all years. Hence, I use the University of Delaware data to provide time varying controls for rainfall and temperature. Because each crop is likely to be impacted differently by rainfall and temperature in a given month, instead of using weather controls by calendar month I create rainfall and temperature relative to the sowing and harvesting seasons for each crop. Specifically, the regressions control for the total rainfall and average temperature

[12]For harvest seasons which overlap two agricultural years I assign the crop cycle to the year in which the majority of the harvest falls. Because some crops such as sugar cane have very long growing cycles, production accrued in year X can begin with a sowing season up to roughly 1.5 years earlier.

[13]The exact dates of Ramadan depend on the sighting of the crescent moon. However, data are not available on when the moon is sighted in each district. Hence, I use a consistent start date for the holiday across all of India for each year and limit the duration of the holiday to 29 days (rather than the possible 30) to generate conservative estimates and ensure that I do not measure overlap with Eid, the holiday following Ramadan.

over the two months preceding each season, during the season itself, and for the two months following the sowing season at the centroid of each district. Because the rainfall and temperature data are provided as a monthly series, these variable are calculated as weighted averages created by summing the number of days in each month for the relevant period (e.g. sowing season) multiplied by the monthly value and dividing the total by the total number of days. Missing values are replaced with imputed values generated from a regression of existing values on district-crop and year fixed effects.

B.4 Calibrating Declines in Agricultural Productivity: "Free Energy" Available for Work

Adjustments to basal metabolic rates and energy use outside of work limit the precision of "free energy" calibrations. However, it is possible to calculate a measure of expected "possible" production based on caloric availability in order to determine whether the observed declines in productivity are roughly congruent with expectations based on energy availability. Rural residents in India were consuming roughly 2240 calories per day in 1983 (Deaton and Drèze, 2009). Researchers have measured the basal metabolic rates (BMR) of rural populations in southern India and have determined that typical basal metabolic rates for low BMI individuals require approximately 1,100 and 1,400 calories per day depending on size and gender (Ferro-Luzzi et al., 1997). Taking the lowest BMR estimates, the strong assumption that all calories not used in basal metabolism are used productively, and the estimated decline in caloric intake for Muslims during Ramadan, individuals have 1140 calories available for work when not fasting and 440 available calories for work when fasting. Passmore and Durnin (1955) review a variety of sources across five countries detailing energy expenditures in different agricultural activities and find that sowing season activities such as clearing brush, digging ridges, and ploughing typically require 4 to 9 calories per minute while harvesting activities such as bundling and threshing typically require 3 to 7 calories per minute. Hence, farm work is likely to burn roughly 180 to 540 calories per hour. Taking an estimate from the middle of this range of roughly 350 calories per hour, a typical farmer would be able to complete roughly 4 hours of active labor when not fasting and 2 hours of active labor when fasting. Accounting for the fact that some energy can be mobilized from fat reserves, these estimates suggest the observed declines in productivity per Muslim individual are consistent with the free energy available.

B.5 Calibrating Expected Water Losses During Ramadan

Perspiration rates depend on a number of factors, key among which are the intensity of the physical activity and factors which influence evaporation rates (i.e., temperature, vapor pressure). The intensity of physical activity can be approximated via the rate at which calories are burned in the activity and the weather variables can be measured directly. A 50 kg individual would be expected to burn approximately 1200 calories in a day of hard farm work during the active labor seasons (Fluck, 1992; Nag et al., 1980). In order to benchmark the expected perspiration rates, I compare this energy usage to the energy consumed by running, one of the most commonly studied activities in which perspiration rates are measured, in similar weather conditions. Rehrer and Burke (1996) reviews the literature and finds that accounting for water intake, running a marathon typically results in a loss of approximately 3% of body weight. Although predicted rather than measured, Sawka et al. (2007) estimate that in temperatures similar to those likely to be experienced by farmers in India running a marathon would result in a loss of 4 to 5% of body weight.[14] However, running a marathon requires roughly 2500 calories or a 50 kg individual, twice the energy required for a day of intensive farm labor. Hence, one would expect roughly half the water losses for farming as well, suggesting an overall loss of roughly 1.5 to 2.5% in body weight. However, two additional factors are likely to reduce sweat rates relative to this benchmark. First, the lower rate of caloric burn for farming will reduce sweat production due to greater passive cooling and less "wasted" sweat lost to dripping (Candas et al., 1979; Shapiro et al., 1982). Second, a higher surface area to mass ratio (negatively correlated with BMI), lower overall weight, low body fat percentage, and acclimatization to heat all improve core body temperature management and substantially reduce sweat rates in hot humid climates (Havenith et al., 1995; Havenith, 2001; Casa, 1999b). This suggests that Indian farmers are likely to have relatively low sweat rates relative to many individuals in the studies cited previously due to their small size, very low body fat percentage, and acclimatization to hot temperatures. Hence, it is unlikely that the 2% of body weight threshold at which decrements in performance begin to be observed is surpassed for a significant number of farmers during Ramadan.

[14]This prediction is based on an ambient temperature of 28 degrees Celsius, or approximately 82 degrees Fahrenheit. The overall mean temperature in the districts included in this study during sowing and harvesting periods was 27 and 24 degrees Celsius respectively (University of Delaware (2013), author's calculations). Although based on a more limited sample, the mean daily maximum temperature over the sowing and harvesting periods was 31 and 29 degrees Celsius, respectively (Climatic Unit Research Database at the British Atmospheric Data Center (BADC), author's calculations.