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# Measuring the Economic Impact of Climate Change on Crop Production in the Dry Zone of Myanmar: A Ricardian Approach

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**Abstract:** Myanmar is the country with the highest economic vulnerability (EV) to climate change in the Southeast Asian region. The dry zone of Myanmar occupies two-thirds of the agricultural lands and it has higher temperatures than elsewhere in the country. Climate change has severe impacts on agricultural production in this region. Moreover, changes in the precipitation patterns increase the likelihood of crop failures in the short-run and production declines in the long run. Therefore, an assessment of the economic impacts of climate change on crop production in the dry zone of Myanmar is very relevant. This paper examines the interactions between agriculture and climate and assesses the economic impact of climate change while using a Ricardian model. A cross-sectional survey covering three regions in the central dry zone: (Magwe, Mandalay, and Sagaing regions) was conducted, yielding a sample of 425 farmers. A non-linear relationship between climate indicators (temperature and precipitation) and revenue of land was found. The marginal effects were calculated by selecting economic and socio-demographic variables. The estimated marginal impacts suggest that the projected changes in temperature will affect the crop productivity of the region. The results also show that the temperature and rainfall components of global warming are both important. Predictions from three global circulation models all confirm that temperature is predicted to increase in all seasons. A significant marginal impact of increasing temperature on the net revenue of farm households was observed in the region. These findings call for policy makers and development planners to articulate the necessary climate change adaptation measures and mitigation options for reducing the negative impacts of climate change. Improved management and conservation of the available water resources could generate water for irrigation purposes and the dissemination of climate smart agricultural practices could lessen the negative impacts of climate change effects on agriculture in the dry zone of Myanmar.

**Keywords:** economic vulnerability; climate change adaptation; ricardian model; agriculture; dry zone of myanmar

## 1. Introduction

Agriculture is one of the most climate dependent human activities, as it is highly sensitive to different hydro-climatic conditions, such as rising of temperature and changes in rainfall. Myanmar, as an agricultural based country, is prone to the adverse effects of climate change. According to Asian Disaster Preparedness Centre (ADPC), it has the highest economic vulnerability (EV) to climate change in Asia [1]. In terms of agro-climatic conditions, Myanmar is a diverse country that exhibits different challenges [2,3]. Historical climatic data show that temperatures are increasing and the length of the wet season and monsoon intensity are decreasing, while rainfall has also become more

erratic. Although climate change impacts on agriculture can already be witnessed, they are likely to be aggravated in the future [1,4]. Myanmar will remain one of the most vulnerable countries [2–5], given the projected changes in extreme weather and climate events, agricultural productivity loss, and sea-level rise.

The Central Dry Zone (CDZ) of Myanmar occupies two-thirds of the agricultural land in Myanmar. The agricultural productivity of this region is crucial for the country, as the agricultural sector alone contributes nearly 40% to the Gross Domestic Product (GDP), making the CDZ an important region for national planning. However, increasing droughts and rising temperatures are clearly affecting agriculture in CDZ [6–10]. Understanding the vulnerability of the agricultural sector to exogenous pressures is important in the development of agriculture and rural areas for the policy makers and development planners. Notwithstanding the importance of the region, the understanding of the magnitude of the impacts of climate change on agriculture in the CDZ is still limited. In the light of the changing climate, Myanmar lacks detailed estimates of climate change and the impacts on agriculture. Therefore, this study estimates the climatic and non-climatic determinants of farm profitability on farm households in the CDZ and assesses the projected impacts of climate change (changes in precipitation and temperature normal) on agricultural performance while using a Ricardian model. The paper is structured, as follows. Section 2 gives an overview of the agricultural system and observed changes in climate in the CDZ, Section 3 reviews the agro-ecological features of the sample districts/regions and Section 4 reviews the data types and methodologies. Section 5 discusses the results and Section 6 concludes and suggests policy options.

## 2. Observed Climate Change Patterns and an Overview of Agriculture in CDZ

The population of the CDZ is approximately 16 million. The region is subdivided in three regions or states: Magwe, Mandalay, and Sagaing [10]. The CDZ is situated in the middle of Myanmar and it is part of the central inner Myanmar basin and lowland area. It is located between 19 and 23° N and between 94 and 96° E. While the CDZ is typically dry, the wide range of soil types, geomorphology, vegetation types, water balance, and human activities makes it a diversified zone. The region has an arid to semi-arid climate. The Bago Yoma Mountain range creates a monsoon' rainfall shadow. Seasonal water scarcity is reported to be the primary challenge for the dry zone region [9,11]. The CDZ receives limited rainfall (500–900 mm) with an unpredictable spatial and temporal variation when compared to country averages (2353 mm). Temperature can be as high as 43 °C, with April and May being the hottest months. The highest mean temperature is around 32 °C and the range between the maximum and minimum temperature is 15 °C [2,3,9,11].

The production of oil crops, pulses, and rice dominate the agricultural system in the dry zone [2,11]. According to Matsuda [12], crop productivity in the dry zone region suffers from the high variation in rainfall. Moreover, the high temperatures reduce the yields of the most important crops. Other constraints to crop production reported include the traditional farming practices, poor quality seeds, lack of investments in inputs and their use (fertilizer, pesticide, fungicide dosages), and uncertain crop prices [6–8,11]. The ongoing adverse changes in precipitation patterns increase the likelihood of crop failures and decrease farm revenues and the incomes of farmers [6,7,13]. As a coping strategy for crop failure farmers in the region typically diversify their agricultural production. Most of the farmers are smallholder subsistence farmers. Approximately 37% of farmers own less than four acres of land [9,14].

## 3. Agro-Ecological Features of the Sampled Districts/Regions

Three agro-ecological zones can be identified based on the type of land (upland or lowland) and the access to irrigation: a zone with intensively farmed croplands with access to irrigation all season, a zone with croplands with access to supplementary irrigation and river beds, and a zone with rain-fed production, including both upland and low-land and extensive rain-fed upland agriculture [9].

There are three main cropping seasons: summer crop, monsoon crop, and post monsoon crop or winter crop.

The characteristics for the dry zone are the clay and sandy soils with high risks of water shortage and wind erosion lead to land degradation and a decline in agricultural production [6,7]. The soil types and rainfall patterns are not conducive to rice cultivation in CDZ, especially in the Magwe region. However, rice is cultivated under irrigation in the Sagaing region. In the CDZ, agriculture is the main livelihood and income generating activity for households. Approximately 11.74 million peoples out of the 16 million of the CDZ live in rural areas and their livelihoods mainly rely on agriculture [10]. A large proportion of the rural population depends on agriculture for their incomes, employments, and food security. With water availability being their main constraint, farmers normally practices deep tillage, manure application, and mulching in order to maximize the water storage during rainfall periods.

## 4. Research Methodology

### 4.1. Data

As mentioned above, a cross-sectional survey was conducted in 16 Townships, which cover five districts and three regions (Sagaing, Mandalay and Magwe) in 2016 to quantify the potential impacts of climate change on agriculture in the CDZ (see Figure 1). This study uses the mean temperatures of the different regions of CDZ. This study uses the mean temperatures in different seasons because it is important to capture the effects of temperature at different key times (three seasons) in the production cycle for farmers. There are three seasons in Myanmar; summer, winter, and monsoon season. Moreover, this study uses the average precipitation and temperature from the past 30 years. These climate data are checked with climate data from regional meteorological departments in the dry zone and additional weighting of these climate data was carried out, so that the data variation of the average mean temperature and precipitation are reduced. All precipitation and temperature variables are expressed by the differences in means across the 30 years of data to ensure that the linear and quadratic terms are not collinear, see also [15]. In addition, projected climate data were also acquired from the World Bank data web portal. Following the three cropping seasons (summer, monsoon, and winter), the strategy of using rainfall averages at each single month permits a more throughout reflection of accumulation of precipitation in soils over a period. Similar to the precipitation, the temperature at key times in the production cycle is important for farmers, and the mean temperatures at each single month are taken into account. The summer season goes from February–May, while monsoon is normally from June-September, and winter is from October–January. Linear and quadratic terms are included since climate variables could have non-linear impacts on net revenues, as in [16,17].

It was observed that there is a significant variation in temperature across the different geographic locations of the Dry Zone. An independent variable that represented the effect of different seasonal rainfall patterns across the year was fitted in our model. This will avoid any serious serial correlation in the independent variables and it will be an effective measure to capture the precipitation effects relative to using a monthly mean.

In addition, this study combines household data with data on long-term climate normals. The structured interviews looked at socioeconomic characteristics, climate change adaptation measures, and institutional characteristics. The interview was carried out face-to-face. At the village-tracts level, the sample villages were randomly chosen and, within the villages the respondents, were also randomly selected. In total, 425 complete questionnaires were obtained. The socioeconomic and demographic characteristics of farm households and crop production data were collected. Moreover, secondary data, such as land use data, and production data of major crops from the Department of Agriculture were also acquired.
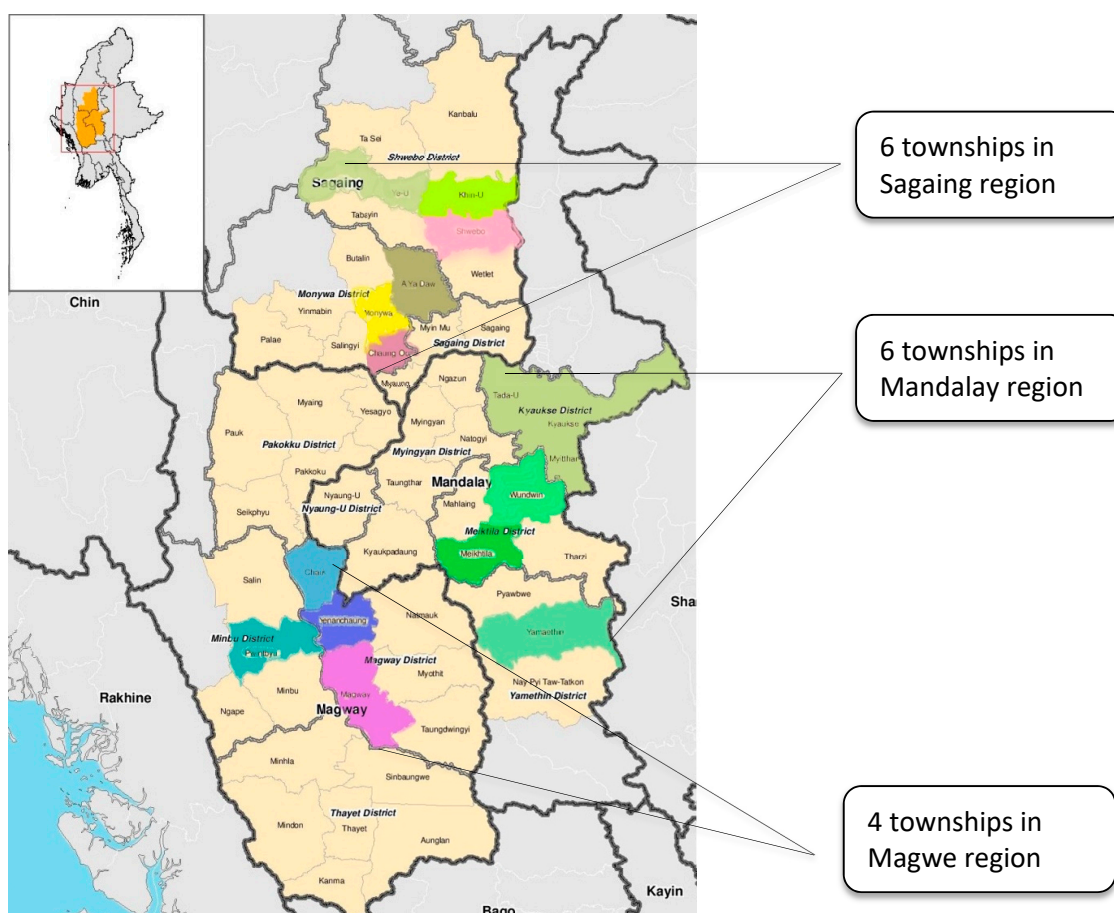
**Figure 1.** Map of the Dry Zone region in Central Myanmar (Source: Myanmar Information Management Unit).

The farmer's fixed costs (i.e., non- cash cost), such as owned cattle and manure cost, their seed storage, and family labor costs were considered, and variable costs (i.e., cash cost), such as hired cattle, farm-machines and labor cost, purchased manure, fertilizer, and pesticide costs, were included in the total farmers costs for production and calculated on a hectare basic. Net revenues per hectare are calculated as the difference between revenues and costs, divided by the number of hectares farmed, see more [15]. Other socioeconomic characteristics of farmers, such as having draught animals, access to irrigation facilities, farm size, and size of households, and distance to market (accessible), were also considered. In the interview with farmers, units that prevailed in the country and region were used and the conversion rate (equivalents in SI units) are shown, as follows: one ac = 0.405 ha, one basket of husked rice = 34 kg, one basket of sesame = 24.5 kg, one basket of pigeon peas = 32.7 kg, and one basket of other pulses (green gram) = 31.3 kg, see also [18]. The current exchange rate of Myanmar Kyat (MMK) was approximately 1 $ (United State Dollars) = 1250–1300 MMK during the surveying period. A production function approach was used to generate the crop revenues of farmers. The reference period for the production data analysis was captured as one-year production cycle from pre-monsoon 2015–2016 to post-monsoon of 2016. The farmers were asked the production of major crops and the diversification of crops upon their owned land over the reference period. For the calculation of farm productivity and profit, data from the previous five years regarding costs and production of specific or major crops, such as rice (monsoon and summer), groundnut, sesame, peas and beans (pigeon peas, black gram, green gram), maize, and sunflower, etc. were acquired from the regional Department of Agriculture. The market prices of different crops at different times (previous five years) were used in the calculation to estimate the net revenue per hectare. The study only estimates the farm income obtained from the major crops. Therefore, the amount of net crop revenues per hectare

of each individual farm household was obtained. The following Figure 2 presents the resulted net farm revenue of crop production ($ per ha) in CDZ. Maize and green gram give the highest return of the farmers by 224$ and 191$ per hectare, respectively. However, farmers report oil crops, such as groundnut and sesame, as their major crops and they were dominated in the CDZ see also [19].
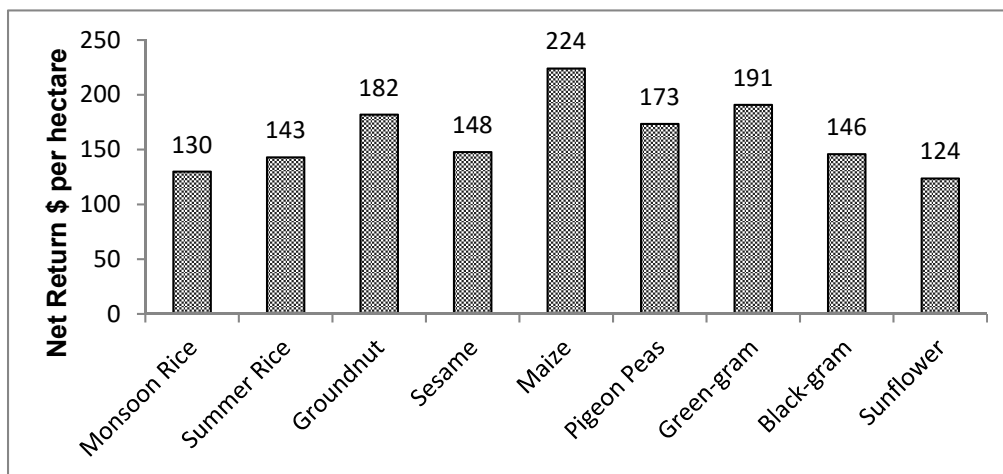


**Figure 2.** Farm revenue of crops ($) per hectare.

Three climate projection models (i.e., PCM (Parallel Climate Model), CGCM3 (Coupled Global Climate Model), and CSIRO (Commonwealth Scientific and Industrial Research Organization Climate Model_ Australia) for Myanmar were used for the scenario analysis to project the future impacts of climate change. Data are presented at 1° × 1° global grid spacing, produced through bi-linear interpolation. The study does not consider the income generated from livestock rearing, and the revenues from the sales of livestock products (milk, butter, meat, etc.), and also excludes subsidies received from government and incomes received from hiring out farm equipment or their own labor. This study excludes these variables, as a part of study focusing on climate change impacts on crop production.

*4.2. Theory: Ricardian Analysis*

In this study, a hedonic approach, known as the Ricardian approach, was used to estimate the marginal effect of various climatic, economic, and other factors on farmland values. This approach is also known as a duality approach, because it examines the relationship between agricultural land values and climate data [16,20–22]. The traditional Ricardian approach has two key assumptions: first, there is a long run equilibrium in factor markets (especially land), but, secondly, there are no adjustment costs, such that land rents fully reflect the value of climate at any given location [23]. Mendelsohn et al. [16] proved that the Ricardian approach could be developed with individual farm data and with district-level data. A lot of research has been carried out while using Ricardian models at the district or regional level [20,21,24,25]. Like other studies, such as Sanghi [26], Kumar and Parikh [27], Kurukulasuriya and Ajwad [15], and Mendelsohn et al. [28], the annual net revenue per hectare is used for representing the agricultural land values, as data on land prices were not available in Myanmar. This study assumes that the net revenue per hectare depends on climate and a number of exogenous determinants.

$$NR = \int P_{LE} \, e^{\propto t} \, d\,t = \int \{\sum P_i - Q_i(X, F, M, G) - R.X\} e^{\propto t} \, dt$$

where: $P_{LE}$ is the net revenue per hectare, ($t$) is the time, and ($\propto$) is the discount rate. We assume that the net revenue per hectare, ($P_{LE}$) depends upon ($P_i$), the market price of crop ($i$), ($Q_i$) the output of crop ($i$), ($R$), a vector of input prices, and ($X$), a vector of purchased inputs (other than land). The crop

output, $(Q_i)$, is in turn a function of the purchased input ($X$); a vector of climate variables ($F$), a vector of labor ($M$), and a set of farm characteristics ($G$), such as market access, livestock asset, and irrigation access, etc. Therefore, the net revenue per hectare depends upon the market price of the crop, the crop output, and a vector of input prices and purchased inputs.

This study assumed that farmers make a series of production choices that aimed at maximizing profit at the farm level. Farm households, however, are price takers and, hence, individual farmers have no impact on market prices [15]. Thus, the estimated specification of net revenues per hectare can be written as:

$$P_{LE} = \beta_0 + \beta_1 F + \beta_2 G + \beta_3 M + \varepsilon$$

where, $(\beta_i)$ are estimated coefficients, $(\varepsilon)$ is the unexplained portion that is assumed to be independent and identically distributed. As said by Kurukulasuriya and Ajwad [15], the potential change in farm profitability due to changes in climate can be estimated as the difference between the changes in net revenues per hectare evaluated with the climate variables set to those before the climate change ($P_{LE}^b$) and after the climate change ($P_{LE}^a$).

In an econometric assessment of the impacts of climate change, the parameter and modeling methods are very uncertain. Blanc [29] pointed that a limiting assumption is that estimates are based on past events, which will continue in the future. In addition, the limitations of this approach are that it explicitly examines crop and farmer responses to climate, as well as implicitly assuming the biophysical and economic adjustments that are imposed by climate change [20]. Thus, studies using a Ricardian analyses need to be carefully evaluated for robustness [20–22,25]. For instance, it is not based on controlled experiments across farms and does not usually fully include all non-climatic factors (soil quality, market access, and solar radiation, etc.) in the model [20,21,24,25]. In addition, the Ricardian model captures the manner in which farmers adjust to climate change over decades, not year by year, and, thus, we assume that the predictions are a snapshot of the long run profits [19].

In addition, Kurukulasuriya and Mendelsohn [30] mentioned that technology variables also need to be carefully evaluated in the model. The access to electricity and irrigation could increase the farm net revenue and reflect either higher technology or better access to market. In this study, the irrigation costs were not counted in the net revenues, but an irrigation dummy was considered for the analysis. The reason is that the utilization of irrigation water in Myanmar is normally free of charge as provided by the government [31]. However, the costs that were related to fertilizer and compost application of each individual farm' households were considered and used in the model. The effects of these strategies on crop net revenue were carefully integrated and calibrated in the model for policy purposes because the farm households can take these decisions individually as climate change adaptation strategies [21]. The Ricardian technique also considers the adaptations as implicit and endogenous and it assumes that each farmer maximizes net revenue subject to the exogenous conditions of the farm [16].

However, this study does not consider future technology changes and changes in the future adaptation strategies following changing climate conditions. In addition, this analysis does not take extreme climate change events into account [21]. Moreover, the Ricardian model does not reflect price effects, and it does not take changes in output and input prices that result from the global changes in production and that might affect farm-level adaptation decisions into account [15,16,32,33]. Therefore, prices are kept constant in the model [15,24,34]. In addition, this study assumed that the only thing that changes in the future is climate, mostly in forecasting climate change impacts. Although many other things, such as population, technologies, institutional conditions, and reliance on agriculture and livestock, will change over the century [21,35], this study does not account for these changes in the future. One of the key assumptions of this method is that farm revenue per hectare is sensitive to climate and a set of exogenous determinants. In this study, it is assumed that climate change will decrease the major crop's yields, which, in turn, will reduce the mean income of the farm households. However, one key assumption is that the return over investment (cost) of the sampled farmers at a given price was considerably similar in all cases of each crop production. However, in this study, the number of diversified crops of the farm' households were objectively considered and interviewed

and, thus, the farm incomes were separately included. Therefore, the data represents the agricultural land values and the model reflects the economic impacts of climate change on agriculture in the CDZ.

## 5. The Regression Results

Table 1 presents the basic summary statistics of the dataset for the relevant variables of the study. The average age of the household head is above 47 years and more than 65 % of the respondents have followed secondary education. Households cultivate approximately 3.56 hectares of land and about 77% of the farmers reported to receive irrigation water. The average distance to the market is about 9.23 miles. Moreover, the data show that roughly about 78% of the farmers use draught cattle for cultivation, which means that the majority of the farmers are cultivating crops in a traditional way. In addition, above 80% of those farms apply compost and manure. Compost and manure are usually by-products of livestock or crop production. The average household counts five people.

**Table 1.** Descriptive statistics: Variables for net revenue regression model.

| Variables | Mean | Std.Dev |
|---|---|---|
| Net Revenue ($ ha$^{-1}$) | 554.969 | 204.815 |
| Summer Temperature (°C) | 29.061 | 2.571 |
| Monsoon Temperature (°C) | 28.166 | 2.363 |
| Winter Temperature (°C) | 22.381 | 2.405 |
| Squared Summer Temperature (°C) | 851.133 | 137.354 |
| Squared Monsoon Temperature (°C) | 798.946 | 122.998 |
| Squared Winter Temperature (°C) | 506.704 | 97.945 |
| Summer Rain (mm) | 82.942 | 32.145 |
| Monsoon rain (mm) | 163.562 | 46.753 |
| Winter rain (mm) | 11.347 | 4.037 |
| Squared Summer Rain (mm) | 7910.354 | 6710.132 |
| Squared Monsoon rain (mm) | 28,933.308 | 15,930.675 |
| Squared Winter rain (mm) | 145.025 | 98.063 |
| Men headed household (1 = male, 0 = female) | 0.77 | 0.419 |
| Size of the cropping area (ha) | 3.556 | 2.661 |
| Farm practicing with draught cattle (1 = yes, 0 = no) | 0.78 | 0.414 |
| Distance to market (miles) | 9.23 | 3.989 |
| Farm with access to irrigation (1 = yes, 0 = no) | 0.77 | 0.420 |
| Farms practicing compose & Manure (1 = yes, 0 = no) | 0.81 | 0.395 |
| Age of the household head (years) | 47.11 | 13.892 |
| Size of the household (number) | 5.64 | 1.946 |
| Educational status of the household head (1 = secondary, 0 = less than secondary education) | 0.66 | 0.495 |

We tested various regression specifications in order to capture the effect of climate variables on different seasons on agriculture in the CDZ of Myanmar. Table 2 presents the resulted findings. The table shows the Ordinary Least Squares (OLS) estimates of the determinants of net revenues per hectare while using two models. Model 1 only take the marginal impacts of the seasonal temperature and precipitation on farm net revenues into account, while model 2 also considers the socioeconomic characteristics of farm households and farm-level adaptation measures. In Model 2, we exclude the insignificant and collinearity associated seasonal temperature and precipitation measures from the model 1. We find that the $R^2$ was about triple from 0.15 when climate and socioeconomic characteristics of farm household are used as in model 2, and thus the inclusion of the socioeconomic characteristics is jointly significant and the model has strong explanatory power. Model 3 was additionally regressed for the parsimonious estimation from the model 2. The test shows that the model was significant at the 1% level. Kurukulasuriya and Ajwad [15] mentioned that demeaning the climate variables does not correct for the multicollinearity that is associated with the linear and quadratic variables. Therefore,

this study has followed the concepts on the Ricardian technique and the literature on the determinants on farm net revenues.

**Table 2.** Determinants of net farm revenue per hectare ($ ha$^{-1}$).

| Variables | Model 1 | Model 2 | Model 3 (Parsimonious Model 2) |
|---|---|---|---|
| Summer Temperature (°C) | −7.179 | −13.325 | |
| Monsoon Temperature (°C) | −7.917 | −16.719 | |
| Winter Temperature (°C) | 211.841 | −12.178 | |
| Squared Summer Temperature (°C) | −0.168 | −0.917 + | −0.220 *** |
| Squared Monsoon Temperature (°C) | −1.392 ** | 0.177 | |
| Squared Winter Temperature (°C) | −3.871 | −1.313 | |
| Summer Rain (mm) | 4.894 | −1.527 | |
| Monsoon rain (mm) | −14.922 ** | −0.636 + | 0.468 * |
| Winter rain (mm) | 92.761 | −0.417 | |
| Squared Summer Rain (mm) | −0.020 + | −0.017 + | −0.009 *** |
| Squared Monsoon rain (mm) | 0.050 * | 0.032 | |
| Squared Winter rain (mm) | −4.421 | −3.796 | |
| Men headed household (1 = male, 0 = female) | | 11.628 | |
| Size of the cropping areas (ha) | | −29.259 ** | −23.390 * |
| Squared size of the cropping areas(ha) | | 2.060 ** | 1.620 + |
| Educational status of the household head (1 = secondary, 0 = less than secondary) | | 51.809 * | 50.466 ** |
| Farm practicing with draught cattle (1 = yes, 0 = no) | | 71.562 ** | 54.408 ** |
| Distance to market (miles) | | −2.155 | |
| Squared distance to market (miles) | | −0.327 | |
| Farm with access to irrigation (1 = yes, 0 = no) | | 190.988 *** | 190.473 *** |
| Farms practicing compose & Manure (1 = yes, 0 = no) | | 62.140 ** | 85.051 *** |
| Age (years) | | 2.086 | |
| Squared age (years) | | −0.016 | |
| Size of the household (number) | | 23.074 | |
| Squared size of household (number) | | −2.285 | −0.493 + |
| Constant (Intercept) | −214.337 | 129.845 | 517.641 |
| Observation | 425 | 425 | 425 |
| R-Squared | 0.156 | 0.471 | 0.438 |
| F-test | 8.515 * | 16.221 *** | 32.297 *** |

+ Significant at 15%, * Significant at 10%; ** Significant at 5%; *** Significant at 1%.

In this study, a marginal impact analysis was conducted to assess the effect of a change in temperature and rainfall on production of major crops. The coefficients that resulted from model 2 were used to estimate the marginal impacts of global warming on net revenues (see Table 2). Increasing temperature in all seasons marginally decreases the crop revenue per ha, while increases in precipitation in all seasons might lead to slight decreases or increases of crop revenue per ha. Therefore, the OLS model implies that increases in temperature are generally harmful in all regions, but increases in rainfall are basically beneficial, although changes of rainfall in the winter season would be harmful to crop production.

In this study, a non-linear relationship between climate and net crop revenue is found, which is consistent with the available literature [16,30,36]. In addition to the climate variables, this study has found many interesting results that are related to farmers' characteristics. Most of the household variables have a significant impact on crop revenue. The size of the cropping areas negatively affects crop net revenues, as the estimated coefficient of crop area suggests that there are increasing returns to scale in farm size. This could be due to the fact that smallholder farmers with less than one hectare of land dominate the agriculture in the dry zone [6,7]. In addition, shortage of farm land is one of the barriers to the uptake of climate change adaptation strategies in the dry zone of Myanmar [37]. A similar result is observed in Kurukulasuriya and Ajwad [15] who stated that households that cultivate

a single crop are less profitable than households that plant multiple crops. Nevertheless, the quadric term of size of the cropping area is likely to positively affect crop net revenue.

This study also considers the household head's education. This could be seen as a proxy for the ability of the households to adopt new technologies, and climate change adaptation measures that are available at the farm-level. Farmers with middle school education have higher net crop revenue per hectare than the farmers with a lower education level. It seems like farmers with middle school education are more likely to adopt new technologies for the purpose of maximizing farm' productivity. However, this study did not directly consider the effect of the level education on the adoption of new technologies at the farm-level. In addition, this study does not consider information about the farmer's experience and its effects on farm productivity. However, the age of the household head was considered as a variable in the model. This study found that age of the household head affects crop revenues in the setting of changing social and environmental conditions. The finding suggests that an increase in age of household head is negatively affecting net revenue, but the relation was not significant. In addition, no significant relation was found for the effects of the gender variable (men headed household). In Myanmar, household members substitute paid labor on the farm. Interestingly, this study did not find an effect of household size on farm profitability, as the available data do not show a significant impact on net revenues. The distance to the market from the farm location is also negative, but is insignificantly related with crop revenue. The quadric term of distance to the market is negatively affects net revenues, but the effects seem to be small. Nevertheless, investing in infrastructure development, such as road, is strongly recommended in the dry zone of Myanmar, as it was also indicated in the findings of Belton et al. [19].

With the use of draught cattle and compost and manure has a positive and significant influence on net revenues. Draught cattle help farmers in land preparation processes and enables farmers to grow crops timely. The application of compost and manure (and green straw) is one of the climate change adaptation measures of farm household in the region. It has a large and positive effect on the net revenues of farm' household in the study areas. The application of compost and manure improves the soil fertility and structure and, therefore, increases crop productivity [38]. In the dry zone region, access to dam irrigation rapidly increased since the mid-1970s. With irrigation, farmers have the potential to obtain more income from farming [19]. This study also finds that farms with access to dam irrigation have significantly higher net revenues. The results indicate that farms with access to irrigation water are more profitable than farms that only relied on rain-fed agriculture. Rain-fed agriculture is less profitable and, thus, productivity will even decrease in the changing climatic conditions in the region. Under such conditions, access to irrigation water could enable farmers to avoid the risks that are related to water scarcity at the farm and reduce the negative effects of increasing temperatures and drought on crop net revenues. Therefore, investing in irrigation development and infrastructure could enable farm households to grow more crops and to obtain more income from farming.

*Predications of Forecasted Climate Scenario on Net Farm Revenue ($ per ha)*

This study uses climate scenarios that are specific to Myanmar to analyze the impact on farm profitability (see Table 3). The future climate change scenarios may have a significant effect on the cropping patterns and crop productivity in the CDZ. Table 4 shows the effects of predicted changes of temperature and precipitation on the net crop revenue per hectare (marginal value changes) over the forecasted scenarios and Table 5 presents the estimated percentage changes. In this section, the stimulated impacts of climate change projections for the Dry Zone of Myanmar were estimated. As mentioned above, three climate change projection scenarios were used to stimulate the impacts of climate change on Dry Zone' agriculture in Myanmar: the PCM, CGCM3, and CSIRO scenarios. The A2 emission scenario was used. Each model predict the temperature and precipitation until 2100, assuming that greenhouse gas emissions continue unabated [15]. The likely impact of climate change on economic or biophysical systems was analyzed by using future climate change scenarios from climate change models [20,22,30]. In this study, future net revenues are calculated by multiplying

the climate coefficients by the future climate. The previous analysis suggests that temperature and precipitation have different effects on the net revenues in the Dry Zone.

**Table 3.** Projected changes in temperature and rainfall by three climate models.

| Region | Temperature (°C) | | | | Rainfall (mm) | | | |
|---|---|---|---|---|---|---|---|---|
| | Summer | Monsoon | Winter | Annual | Summer | Monsoon | Winter | Annual |
| PCM | | | | | | | | |
| Value in 2020-39 | 0.97 | 0.68 | 0.77 | 0.81 | −3 | −1 | −8 | −4 |
| Value in 2040-59 | 1.35 | 1.04 | 1.22 | 1.2 | 12.7 | 6.8 | −5.6 | 4.6 |
| Value in 2060-79 | 2.14 | 1.84 | 1.99 | 1.99 | 22 | 11 | −5 | 9 |
| Value in 2080-99 | 3.4 | 2.8 | 3 | 3 | 13 | 16 | −14 | 5 |
| CGCM3 | | | | | | | | |
| Value in 2020-39 | 1.5 | 1.1 | 1.4 | 1.3 | 4.7 | 10.8 | 0.1 | 5.2 |
| Value in 2040-59 | 1.9 | 1.8 | 1.9 | 1.8 | 9.3 | 20.8 | 1.9 | 10.7 |
| Value in 2060-79 | 2.65 | 2.51 | 2.84 | 2.67 | 22.5 | 19 | −1.2 | 13.4 |
| Value in 2080-99 | 3.4 | 3.3 | 3.8 | 3.5 | 23.9 | 32.1 | 0.5 | 18.8 |
| CSIRO | | | | | | | | |
| Value in 2020-39 | 1.5 | 1 | 0.8 | 1.1 | −10.6 | 12.9 | −3.2 | −0.3 |
| Value in 2040-59 | 2.2 | 1.7 | 1.6 | 1.8 | −10.1 | 20.9 | −2.2 | 2.9 |
| Value in 2060-79 | 3.05 | 2.41 | 2.5 | 3.2 | −11 | 22 | −3 | 3 |
| Value in 2080-99 | 4.5 | 3.3 | 3.2 | 3.7 | −19 | 49 | −3 | 9 |

**Table 4.** Marginal effect of temperature and precipitation on net revenue per hectare ($ ha$^{-1}$).

| Scenario Projection | Temperature Effects | | | Rainfall Effects | | |
|---|---|---|---|---|---|---|
| | Summer | Monsoon | Winter | Summer | Monsoon | Winter |
| pcm20-39 | −12.9253 | −11.3689 | −9.37706 | 4.581 | 0.436 | 3.336 |
| pcm40-59 | −17.99 | −17.39 | −14.86 | −19.3334 | −2.97261 | 2.328872 |
| pcm60-79 | −28.57 | −30.84 | −24.19 | −33.0167 | −4.88543 | 2.037754 |
| pcm80-100 | −45.9241 | −46.0207 | −36.6071 | −19.4177 | −6.7856 | 5.964477 |
| cgcm3_20-39 | −19.9875 | −18.3909 | −17.0492 | −7.1769 | −4.7088 | −0.0417 |
| cgcm3_40-59 | −25.00 | −29.35 | −22.67 | −14.2011 | −9.0688 | −0.7923 |
| cgcm3_60-79 | −35.33 | −41.97 | −34.62 | −34.3306 | −8.26326 | 0.493901 |
| cgcm3_80-100 | −45.7545 | −55.3093 | −45.8658 | −36.5302 | −13.9871 | −0.19457 |
| csiro_20-39 | −19.9875 | −16.719 | −9.7424 | 16.1862 | −5.6244 | 1.3344 |
| csiro_40-59 | −29.04 | −28.61 | −19.63 | 15.34708 | −9.1094 | 0.929108 |
| csiro_60-79 | −40.62 | −40.33 | −30.40 | 16.04482 | −9.80657 | 1.307409 |
| csiro_80-100 | −59.7436 | −55.4882 | −38.5124 | 29.41234 | −21.4432 | 1.268073 |

**Table 5.** Climate predictions of Special Report on Emissions Scenarios (SRES) from 2020–2100 years.

| Climatic Scenarios | 2020–2039 | | | 2040–2059 | | | 2060–2079 | | | 2080–2099 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Changes of temperature on crop net revenue (% changes)** | | | | | | | | | | | | |
| **Climate change model/Seasons** | **Summer** | **Monsoon** | **Winter** | **Summer** | **Monsoon** | **Winter** | **Summer** | **Monsoon** | **Winter** | **Summer** | **Monsoon** | **Winter** |
| PCM | −10.0 | −8.8 | −7.2 | −13.9 | −13.4 | −11.5 | −22.1 | −23.8 | −18.7 | −35.5 | −35.5 | −28.3 |
| CGCM3 | −15.4 | −14.2 | −13.2 | −19.3 | −22.7 | −17.5 | −27.3 | −32.4 | −26.7 | −35.3 | −42.7 | −35.4 |
| CSIRO | −15.4 | −12.9 | −7.5 | −22.4 | −22.1 | −15.2 | −31.4 | −31.1 | −23.5 | −46.1 | −42.9 | −29.7 |
| **Changes of precipitation on crop net revenue (% changes)** | | | | | | | | | | | | |
| | **Summer** | **Monsoon** | **Winter** | **Summer** | **Monsoon** | **Winter** | **Summer** | **Monsoon** | **Winter** | **Summer** | **Monsoon** | **Winter** |
| PCM | 3.5 | 0.3 | 2.6 | −14.9 | −2.3 | 1.8 | −25.5 | −3.8 | 1.6 | −15.0 | −5.2 | 4.6 |
| CGCM3 | −5.5 | −3.6 | 0.0 | −11.0 | −7.0 | −0.6 | −26.5 | −6.4 | 0.4 | −28.2 | −10.8 | −0.2 |
| CSIRO | 12.5 | −4.3 | 1.0 | 11.9 | −7.0 | 0.7 | 12.4 | −7.6 | 1.0 | 22.7 | −16.6 | 1.0 |

Temperature is predicted to increase in all seasons, according to the PCM model. A significant marginal impact of increasing temperature on the net revenue of farm households was observed. Thus, using the PCM climate model suggests that increasing temperatures will affect farm households in the CDZ. If the temperature increases 2–4 °C during the period 2060–2100, the likely impacts of increasing temperature on crop net revenue will range from −18% to −35%. In the PCM climate model, precipitation is projected to increase until 2070. However, precipitation is predicted to decrease again in the last 20 years of the century (2080–2100), especially in the summer and winter seasons. In the winter season, the crop net revenues could increase by 1.5% to 4.5% in the first period, but decreases of 5% to 25% in crop net revenue are also expected during the period 2060–2100. As stated by Kurukulasuriya and Mendelsohn [30], climate change is not likely to be uniform with some areas getting dryer and other wetter. This study indicates that the climate change scenarios by the PCM model were not uniform. However, the PCM scenarios are relatively mild when compared to other climate scenarios, such as CGCM3 and CSIRO.

In addition, the results from the CGCM3 climate model point out that increasing temperature will have impacts on crop revenue of farmers in CDZ. However, temperature is predicted to slightly decrease in the first quarter of the century, but it will increase again afterwards. Until 2050, there will be not much change in net revenue, but a significant impact of increasing temperature on net revenue of farm households in the last 40 years of century (2060–2100) was observed while using projections of the CGCM3 climate model. According to the data resulting from the CGCM3 climate model, the negative impacts on crop revenue by increasing temperatures range from 15% to 42%. Positive net revenues of crops were observed by the projected increase in rainfall in winter season. However, a negative impact of projected changes in the precipitation on crop net revenue was observed in summer (ranging from 5% to 28%) and monsoon seasons (ranging from 3.6% to 10%). These predictions more or less show the magnitude and direction of future impacts on agriculture [20,24,30].

The CSIRO climate model was additionally formulated for understanding the trends and potential impacts of a changing climate on crop revenues of farmers in CDZ. Temperature is predicted to be stable until 2040, but it is projected to increase after that until 2100. Again, there will not be many changes in net revenue until 2050, but a significant impact of increasing temperatures on net revenue of farm households in the last 50 years of century was observed when using the CSIRO climate projections. The CSIRO climate model projects the monsoon precipitation to increase until 2100. However, there will not be much fluctuation in the precipitation in the winter and summer seasons. Farmers are expected to receive positive net revenue from farming, due to the changes in precipitation in the summer and winter season. In the monsoon season, a slightly negative impact on net revenue is predicted, with changes from 4.3% to 16%. However, farm households will have a lower crop net revenue in all seasons and changes are expected from 7.52% to 46% because of the projected changes in temperature. Therefore, all of the models show that climate change will have serious impacts on crop production in the CDZ.

## 6. Conclusions and Recommendations

This study examines the effects of climate change in different regions in the Dry Zone of Myanmar on crop production, based on a cross-sectional analysis. The empirical results from this study showed that the net revenue per hectare was sensitive to marginal changes in climate variables (temperature and precipitation). The estimated coefficients from the OLS model were presented to show the effects of climate change variables and farm' household characteristics on crop net revenue. The prediction of the impact of climate change on crop production is just an estimation of what would likely be the impact on the economy of farm households, but it is not a prediction of what may actually occur in the future. The crop net revenues per hectare of farm households in the CDZ were changed along with the marginal changes in climate variables (temperature and precipitation). The results from the regression analysis reveal that improving access to dam irrigation is necessary for the farmers to cultivate crops in hard climatic conditions. Therefore, it is also recommended to invest in the development of irrigation

facilities in the region, so that irrigation water can be utilized from the purpose of development of agriculture and rural areas. Moreover, improving access to markets would lessen the negative impacts of climate change on agriculture. In addition, the application of recommended climate change adaptation strategies, such as systemic utilization of manure or compost, could lead to an increase in crop revenues.

The marginal effects of climate change on crop revenues suggest that climate change might have very different effects on different farmers in CDZ. Predictions from the three global circulation models confirm that global warming will have a substantial impact on the net crop revenue in the dry zone of Myanmar. Overall, this paper suggests that there is a large range of impacts on agriculture in CDZ. However, these results may be relatively biased by our net revenue specification, in which assumptions were made regarding constant prices or full adaptation, or that does not take into account annual capital cost, and family labor costs. In addition, the Ricardian model is not suited to identify the perceptions of farmers on current climate conditions and their adoption of climate change adaptation strategies in the future, as well as policy interventions and, thus, this study cannot predict if the agriculture in CDZ of Myanmar might be changed in the near or mid-terms in the future. However, our study has provided empirical based research findings from the perspective of climate change impact assessment on farm incomes in dry zone of Myanmar. We can conclude that prevention is more effective than treatment as the CDZ experiences the negative consequences of climate change and variability and, thus, investment in agricultural research and rural development projects, such as integrated water management projects, sustainable agriculture, and organic farming, is strongly encouraged, so that the adaptive capacity of farmers can be increased and climate change vulnerability be reduced. In addition, policy makers and development planners should articulate or implement climate change adaptation measures and mitigation options to reduce the negative impacts of climate change on agriculture in the Dry Zone of Myanmar.

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