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Analysis

Regionalization of climatic factors and income indicators for milk production in Honduras

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ABSTRACT

The temporal and spatial distribution of dry and wet seasons is drastically limiting forage and agricultural production in Honduras. A regional overview on how these patterns influence the income of different types of milk producers was non-existent and would be a beneficial tool for targeting policies and development interventions. This paper examines the regionalized incomes derived from milk production by relating dry season length to milk production parameters for dairy farms. Cattle farms were assessed using two samples. Milk production in the dry and wet seasons was characterized by monthly net income from milk per cow. Sample A (97 farms) was classified according to a) herd size classes and b) performance in dry season milk production. Sample B (30 farms) assessed advanced farms that used more forage technologies than the others.

The income from milk was related to environmental conditions by means of a countrywide map based on dry season length. The map was created by estimating the water balance for each month in a GIS. Yearly income from milk/cow was regionalized for the farm classifications and combined with agricultural census data.

Results of the GIS analysis show a detailed zoning of dry season length and yearly income per cow from milk. Climate-income maps quantify the income ranges of the examined groups of farms.

Climate change models predict temperature rise and decreasing precipitation for Honduras. In view of these trends the results can be used for an interpretation of farm vulnerability and resilience to climate change.

1. Introduction

Large parts of Honduras are characterized by a prolonged dry season, varying in length between the moist zones of the North, seasonally dry livestock zones in the center and the dry South. This temporal and spatial seasonality is limiting forage and agricultural production gradually and as a consequence, the income of farmers depends on climatic conditions. Thus an interdisciplinary research approach is needed when it comes to relate specific climatic conditions to economic indicators for milk production.

Detailed information on climatic patterns in Honduras is important, because Central America's milk production in the dry season is about 40% lower than in the rainy season, when feed resources from green pasture are abundant (Argel, 1999; Holmann, 2001). Low quality and quantity of feed as well as the low genetic potential for milk production of the commonly used dual-purpose cattle (i.e. cattle for beef and milk production) lead to the sharp decline in milk production during the dry season. (Suttie, 2000; Fujisaka et al., 2005).

Farmer's live histories tell that milk production systems in Honduras mainly originated from extensive ranching systems. In the past when land was abundant in Honduras ranching enabled farmers to cope with difficult ecological conditions of prolonged dry seasons. In ranching, the use of labor is considerably less intensive than in other agricultural land use purposes (Williams, 1986). However, over the past years a high demand for dairy products has resulted in a general change of farming systems from ranching, with its primary product beef, to increased importance of milk production. Between 2001 and 2003, milk production in Honduras lagged 14% behind consumption (FAO, 2005) and projections to 2020 foresee an annual growth of milk demand by 2.9% for developing countries (Delgado, 2005). Such conditions may be an opportunity for smallholder farmers to increase their incomes but low market participation (Kyeyamwa, et al, 2008) and the technological level of their production temper the optimism.

Yet, cost efficient milk production under the given climatic conditions of Honduras is much more demanding than ranching. So far, many farmers have shifted to milk production but did not yet fully account for this in herd management and feeding strategies. In both, traditional and modern farming systems of Honduras, the profitability of milk production depends on climatic factors. Moreover, for many farms the income from milk sales provides the only continuous cash

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flow, which allows investing in other farm activities such as the cultivation of cash and subsistence crops, general improvements of the livestock system, the adoption of improved forage options or the improvement of cattle breeds.

Regionalization of income disparities is able to efficiently visualize and present the complex situations. Policy and development interventions can be planned easier when the situation and possible impact of changes is modeled spatially.

Only few papers used regionalization for the case of Honduras and none of them related climatic factors to the income from milk. Jansen et al. (2006) used a combination of biophysical factors to regionalize livelihood strategies of rural families in Honduras. Land use change models (Munroe et al., 2002) were set up linking panel data on land cover changes derived from satellite imagery to socio-economic conditions.

To assess regional trends, specific socio-economic indicators need to be made available across larger regions, however data collection is often restricted to surveys in limited study areas. Regionalization of socio-economic data tackles these scale related constraints by taking into account that farms act in their spatial setting which is determined by a sum of conditions, making up the frame for production (Lentes, 2004, 2006). Many of these factors are physical site conditions, like climate, soil quality, terrain, slope and water availability throughout the year. Regionalization makes use of the interplay between economic and ecological systems, following the assumption that indicators derived from surveys are similar in other areas with similar physical site conditions. For example an income indicator for milk production in the dry season that was assessed in an area with prolonged dry season can be used to represent income in other areas with similar ecological constraints. The site conditions, represented by spatial variables, can be used for regionalization if a dependency with socio-economic indicators can be established. Then, socio-economic indicators can be extrapolated to the coverage area of the spatial variables.

Against this background the objective of this paper is to relate the effect of dry season length to the income from milk per cow for farms of distinct cattle herd sizes and performance classes and to regionalize these data. A further objective is to demonstrate how the average income from milk to be expected in a department can be assessed when agricultural census data, dry season length and survey results are combined.

The spatial spread of the profitability of dairy production is mapped and enables regional targeting of forage options considering specific groups of farms in the regions.

2. Material and Methods

The approaches for regionalization presented in this paper use the length of the dry season as a spatial and temporal variable. The returns from milk during the dry and wet seasons were assessed on 127 farms to distinguish socio-economic systems and for the approximation of the yearly income depending on dry season length (Lentes et al., 2006, 2007).

2.1. Climate Data Generation and Water Balance

The minimum of meteorological data required for setting up a water balance model consists of monthly mean temperatures and mean monthly rainfall (Schöninger and Dietrich, 2003).

Available climate datasets (Mitchell and Jones, 2005; CGIAR-CSI, 2006) are designed for continental scale analyses and are thus too coarse for the requirements of this study. Although the Ministry of Natural Resources and the Environment of Honduras SERNA (2005) published a map of annual rainfall for Honduras, it was not available in a processable form and further data gaps on monthly mean temperatures had to be filled. This was achieved by combining three data sources, which are:

1. Climate station data provided from SERNA (2007a,b) and the national meteorological institute (SMN, 2007).
2. Digital elevation data accessible from CSI-CGIAR SRTM.
3. Climate data generated for 412 points with databank included in the software MarkSim.

MarkSim is a computer tool that generates simulated weather data for crop modeling and risk assessment for the tropics. "MarkSim works from a set of interpolated climate surfaces to fit a Markov model to the estimated climate data. It uses a third order model with a special stochastic resampling of the model parameters to realistically simulate the rainfall and temperature variances for almost anywhere in the tropics." (Jones, 2001). For a good estimation, MarkSim requires the coordinates of the point and its respective elevation information.

Elevation information was obtained from a digital elevation model (DEM), (CGIAR-CSI, 2004). This DEM has a resolution of approximately 90 m and the inherent error of the elevation information is specified not to exceed 16 m.

To provide simulated weather data for Honduras, a set of 383 points, which corresponds to the resolution of MarkSim's climate grid surface was generated, using GIS. To represent the area around these points, the mean elevation inside an 8200 m buffer was calculated from the DEM. For areas with steep gradients of rainfall and temperature, 29 additional points were selected and fed to the climate model. The output of MarkSim was made accessible for calculations with spreadsheet software by means of a small application.

The model results were compared to data, which was available from the meteorological stations of SERNA (2007a,b) and SMN (2007), using their locations and altitudes as model input. For mean monthly rainfall this was done for 17 stations. Measured mean monthly temperature data are scarce. Only six stations measure temperature but linear correlations between measured and simulated temperatures are highly significant and were used to correct the model output.

The dataset of mean monthly temperature and rainfall for 430 points contains:

- 412 input points for MarkSim (383 regularly spaced and 29 additional), with mean monthly rainfall and corrected mean monthly temperatures.
- 7 points from meteorological stations with measured mean monthly temperature and mean monthly rainfall.
- 11 points from stations with measured mean monthly rainfall and MarkSim generated and corrected temperature data.

2.2. Dry Season Length Approximation

The length of the dry season is the period in which evapotranspiration (Et) exceeds precipitation i.e. the period in which the amount of available water is not sufficient for the growth of vegetation. To enable the dry season assessment for livestock holders pastures were selected as reference plants for dry season assessment. For comprehensive descriptions of methodologies to estimate evapotranspiration and definitions for the water balance, see Allen et al. (1998), or Schöninger and Dietrich (2003).

The empirical method of Thornthwaite (1948, cited in Schöninger and Dietrich 2003) was applied for the countrywide Et assessment, creating calculation routines in Excel and applying them to each location for which the climate data was generated. The Thornthwaite method copes with the minimum data requirements, relying on empirical relations between reference evapotranspiration and air temperature, based on measurements from various climate zones (Schöninger and Dietrich, 2003). Other methods for evapotranspiration calculations, like the FAO Penman-Monteith (Allen et al, 1998) require data of meteorological elements not available for many development countries (Pereira and Pruitt 2004). It is known that the Thornthwaite method tends to underestimate Et_0 under arid

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conditions (Pelton et al., 1960; Stanhill, 1961) and that it overestimates Et_0 under the equatorial humid climate of the Amazon region (Camargo et al., 1999). Those studies mainly focused on daily Et_0 estimation. Since only monthly averages were used for the regionalization, the inaccuracy of the method was tolerated.

$$Et_0 = 16c\left(\frac{10T_i}{I}\right)^a \quad (1)$$

$$I = \sum_{i=1}^{N} (T_i/5)^{1.514} \quad (2)$$

$$a = 6.7*10^{-7}I^3 - 7.71*10^{-5}I^2 + 1.79*10^{-2} + 0.49 \quad (3)$$

$$c = (d/30)*(h/12) \quad (4)$$

Where:

Et_0	reference evapotranspiration mm per month
T_i	mean surface air temperature in month i (°C)
I	heat index defined in Eq. (2)
a	in Eq. (1) is a function of the heat index (I)
c	correction factor for month length and daylight duration Eq. (4)
d	length of month in days
h	hours of daylight at the 15th of the month.

To obtain crop specific evapotranspiration (5) (Et_{crop}), Et_0 was corrected using a crop specific correction factor (K_c). For the scope of this study the K_c for rotated grazing land higher than 15 cm, as provided by (Allen et al., 1998) was used.

$$Et_{crop} = Et_0 * K_c \quad (5)$$

Water surplus (6) is the difference between rainfall and evapotranspiration of the respective land cover. Whenever water surplus was negative, the month was defined as dry.

$$Water\,surplus = Rainfall - Et_{crop} \quad (6)$$

Formulae (1)–(6) were applied to the mean monthly rainfall and temperature data of the 430 sample points that cover Honduras. Kriging interpolation was used to fill the information gaps between points for which climate data were generated. Thus it was possible to create climate and dry season length surfaces from the sample points.

Kriging interpolation is a linear estimation procedure introduced by Matheron (1963). In Kriging the value of the variable at the location of estimation is calculated from the weighted mean of the surrounding sample points. The weights of the sampled points are calculated to perform optimally to reach the smallest variance in the estimation error. For the interpolation, the Kriging plug-in of Boeringa (2000) for ArcView GIS was used. The grids were calculated considering the variance of the 12 neighboring sample points and their distances to the point of estimation. A linear trend in the sample data was assumed for the model.

2.3. Sampling and Calculation of Socio-Economic Indicators

The data used for this paper were collected by means of a comprehensive socio-economic questionnaire, which covered all parts of the farming system (*e.g.* family members, education levels, employment, land use inventory, perennial and annual crops, pastures, cut-and-carry forages, forage cultivation, forage conservation, beef production, milk production, poultry and off-farm work). This enabled to take into account the diverse structures of farms and the different feeding strategies.

The total number of cattle farms in Honduras is reported to be 86,829. Their main focus of production lay in beef (5.8%), milk (44.2%), beef and milk (33.5%) and others (16.5%) (INE, 2001). The sampling plan applied for the collection of micro level farm data covered two study areas in representative zones in the departments of Olancho and Yoro. These study areas were selected after consultation of local experts to be typical in terms of herd composition and management in parts of Honduras with prolonged dry seasons. The income indicators used for regionalization were assessed in 2005 and 2006 from the two sub-samples A and B.

In sub sample A the economic conditions of the **typical livestock holder** were assessed for randomly selected farms. The sample covers 69 farms in Olancho and 28 in Yoro.

For sub-sample B, 30 farms, referred to in the text as **positive deviances** were selected using expert knowledge provided by local extension staff. In this study, the term positive deviance does not exclusively mean "success story", as it is used by Biggs (2008). On these farms adoption of diverse forage options is more obvious than on the typical farms from sample A. However, the advanced use of forage options did not necessarily mean that the farms took full advantage of the technologies adopted and that this would translate into higher income.

Forage technology adoption is seen as a necessary entry point for cattle farms to improve resource use efficiency but not as the sole technology necessary to reach an integrated development of the farms. Extra large farms (>100 cattle head) were not accepted as positive deviances, because the availability of financial resources was not comparable to the typical Honduran farm.

The emphasis of this paper lies on the dairy enterprise, yet other parts of the farming system (beef and crops) were also considered in order to characterize the systems and to highlight the importance of milk production.

To obtain the net income of a production system, all production costs were deduced from the gross income. Production costs include all purchased inputs and farm inputs, costs for renting machinery, services and the opportunity cost of family labor. This means that the income for each person working on the farm is valued with equivalent wages like the wages paid for hired labor.

The indicators net income per cow from milk for the dry and for the wet season was chosen to measure the performance of the dairy enterprise in both seasons. Another indicator, the production cost per liter of milk in both seasons was used to underline the cost of milk production in the groups.

Classifications according to cattle herd size and performance serve to make farms comparable throughout systems and sizes. Farms from sample A were classified, compared to each other and to farms of sample B.

2.4. Classification Procedure

Two classification methods were applied to farms of sub-sample A: herd size and performance in dry season milk production.

Table 1 shows 5 herd size classes based on a modification of the classes used by SECPLAN (1994) and a class of positive deviances, (sub-sample B) which contains farms of various herd sizes.

Table 1
Herd size definition, according to the number of cattle per farm.

Herd size category	Number of cattle per farm
Very small	1–9
Small	10–19
Medium	20–49
Large	50–99
Extra large	>100

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Performance in dry season milk production was based on the dry season net income from milk per cow per month. Performance classes were defined as follows.

- Very low performers (31 farmers): Cost of milk production exceeded the revenue.
- Low performers (17 farmers): Positive observations below the median.
- Medium performers (29 farmers): Observations between the 50 and 80% percentile.
- Top performers (20 farmers): Observations above the 80% percentile.

The positive deviances (30 farmers of sub-sample B) were considered separately.

2.5. Regionalization of Indicators

For the regionalization of income from milk production, the seasonality of the net income plays a crucial role.

For the performance and herd size groups, the indicator net income from milk per cow per year is the sum of the dry and wet season income per cow. Where dry and wet season income were calculated by multiplying the corresponding average income figures with the number of months in each season.

The regionalization of the average net income per cow per year in the departments of Honduras used the last complete agricultural census (SECPLAN, 1994) to determine the share of each herd size class in the each department. The spatial units of this publication are the departments. Five years later, INE (2001) published agricultural statistics for 7 representative regions covering Honduras. This publication has the disadvantage that the spatial resolution is more coarse, compared to the 1994 census.

The 1994 Census data were collected before hurricane Mitch. In the year after the disaster, cattle population had declined to 82.5% of the 1994 population. Annual growth rates are reported to be 2.5% for the post Mitch years between 1999 and 2001. Supposing that from 2001 on till 2005, the year of the socio-economic survey undertaken for this study, growth rates have been similar, the livestock population would have reached the pre Mitch level again by 2005. If we further suppose that this growth has not lead to a drastic shift in herd size composition of farms, the inaccuracy of the data from 1993 can be tolerated. Although there is uncertainty about this development, the 1993 data are still the best available information on herd size composition in the departments of Honduras. To make the analysis more reliable two factors were considered: a) Instead of using the numbers of cattle reported in the statistics, only the numbers reported for farms in herd size classes were used. b) The seven herd size classes of SECPLAN and INE were aggregated to 5 classes. This was done by merging classes for very small farms (1–4 and 5–9 cattle) to the class 1–9 cattle and by merging the classes for the very large farms (100–499 and >500 cattle) to >100 cattle. Together with the result of the productivity assessment from the farming systems survey, census data were used to extrapolate the income situation of the dry and wet season from the survey population to the population of the department.

The department wide average net income/cow/month was calculated as follows:

$$Y_{\text{dry}} = \sum_{i=1}^{N=4} \frac{F_i}{F_{\text{tot}}} {*} I_{i\text{dry}} \quad (7)$$

$$Y_{\text{wet}} = \sum_{i=1}^{N=4} \frac{F_i}{F_{tot}} {*}\, I_{i\text{wet}} \quad (8)$$

where:

Y_{dry} Region wide average income/cow/month in the dry season
Y_{wet} Region wide average income/cow/month in the wet season
F_i Number of farms in farm size class i
F_{tot} Total number of farms
$I_{i\text{dry}}$ Net income/cow/month of dry season for farm size class i
$I_{i\text{wet}}$ Net income/cow/month of wet season for farm size class i.

Formulae (7) and (8) yield the average income values for the dry and wet season for each data point (Grid cell). These depend on the proportion of each herd size class in the department's cattle farmer population. The region wide average income per month of dry season was calculated for each department by creating two grid themes: a) the respective value for Y_{dry} for each department and b) the respective value for Y_{wet} for each department. These two grid themes were processed with the grid obtained for dry season length to calculate the average yearly income from milk per cow as described for the herd size and performance classifications.

3. Results

Results are presented in three sections: a) The assessment of the dry season length, b) the classification of sampled farms according to farm size and the performance indicator and c) results of the three regionalization approaches.

3.1. Dry Season Length

Temperature and rainfall data of stations were compared to the corresponding result for their locations as generated with MarkSim. A set of linear regression models, one for each month, was created with SPSS to correct the MarkSim data with station data. These regressions on temperature yielded high explanatory qualities in terms of R-square, since altitude is of major importance when explaining temperatures. On what concerns the rainfall data, the differences between the model results and the measured rainfall are on average small and tolerable.

Fig. 1 shows the annual rainfall distribution for mainland Honduras as modeled with MarkSim, interpolated and mapped with GIS.

While the north and especially the northwest receive most rain, the central departments of Honduras are marked by annual rainfall sums between 1400 and 1000 mm. Moisture islands inside the territory consist of mountain areas shared between Comayagua and Santa Barbara, where higher elevations yield more rain and the area around Lake Yohoa. In the slipstream areas behind the coast parallel mountain ranges of the North, there is an abrupt drop of annual rainfall sums. A distinct moisture gradient is to observe in Olancho from the southwest to the northeast and further throughout the departments of Gracias a Dios and Colon to the Caribbean coast, where annual mean temperatures are also higher than inside the country (Fig. 2). Although favored by high rainfall sums, much of this area is a protected biosphere reserve and in most of the unprotected part access is highly limited. In some areas on the Caribbean coast rainfall sums map turned out not precise, according to field experience. These estimation errors can be attributed to an edge effect of the interpolation. Such estimation errors occur along the geographic margins of the input datasets, e.g. when gradients between the last measurement points on are steep. Although the edge effect would not have affected the results greatly, dry season length was adjusted to surrounding areas using field experience of local experts.

The dry season lengths (Fig. 3 and Table 2) were calculated from the difference between evapotranspiration, as assessed with method of Thornthwaite (1948) and the annual rainfall.

Dry seasons shorter than 3 months cover about 15% of the land and are characteristic for the northern part of the country near the coast, where elevations are below 200 m (Fig. 3). Short dry seasons inside the country are characteristic for mountain areas e.g. those shared

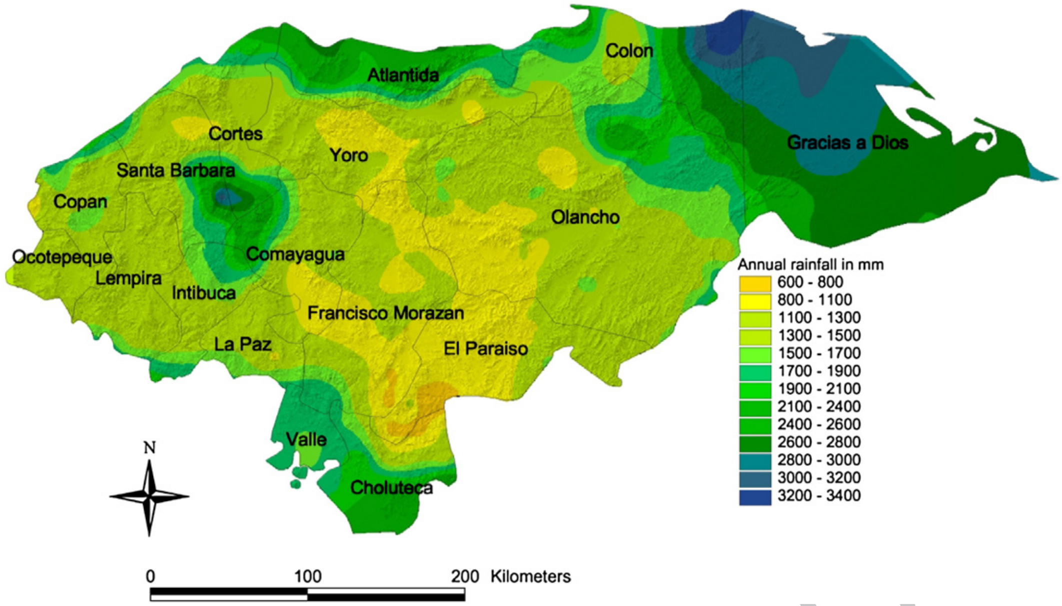

Fig. 1. Annual rainfall.

between Comayagua and Santa Barbara, where higher elevations yield more rain and the area around Lake Yohoa.

In the slipstream areas behind the coast parallel mountain ranges, there is an abrupt drop of annual rainfall sums and an increase of dry season length.

About 80% of Honduras was mapped with dry seasons lengths between 3 and 7 months. In the central departments of Yoro, Francisco Morazan, Comayagua El Paraiso and in most of Olancho, as well as in the eastern departments Ocotepeque, Lempira and La Paz dry a dry season length of 4 to 7 months is most characteristic. Where the dry season is shorter, cooler temperatures and increasing rainfall are due to higher elevations.

About 4% of Honduras was mapped with dry seasons longer than 7 months. The driest areas are found in intra mountain valleys, e.g. in the South of El Paraiso, bordering Choluteca, or in rain shadow-influenced environments, such as in the South east of Olancho. Although the South of Honduras shows higher annual rainfall than e.g. the central departments, it has longer dry seasons, because rainfall is concentrated on short periods of the year, in which heavy rainfall events occur. This region also has higher temperatures than the central departments (Fig. 2).

The climate model seems to overestimate dry season length in the driest parts and it seems to under estimate dry season length in the wettest parts of the country. However, these over- and undershoots could not be confirmed by data measured on meteorological stations and cover a comparatively small area.

From the calculation of dry season length, it can also be assessed in which months and where consecutive dry months occur. This showed that the start of the dry season is spatially more variable than the end of the dry periods. The areas, where the dry season starts first (in November) are located in the south along a strip oriented from south east on the border to Nicaragua to the west of the country on the border to El Salvador and Guatemala. In the central parts of the country dry season starts between December and January. Where dry

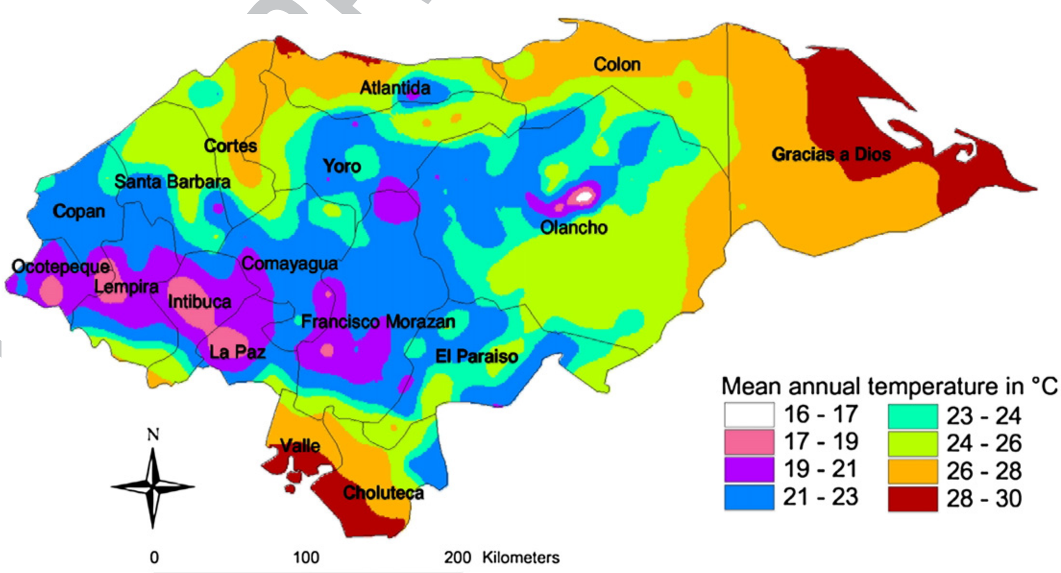

Fig. 2. Annual mean temperatures.

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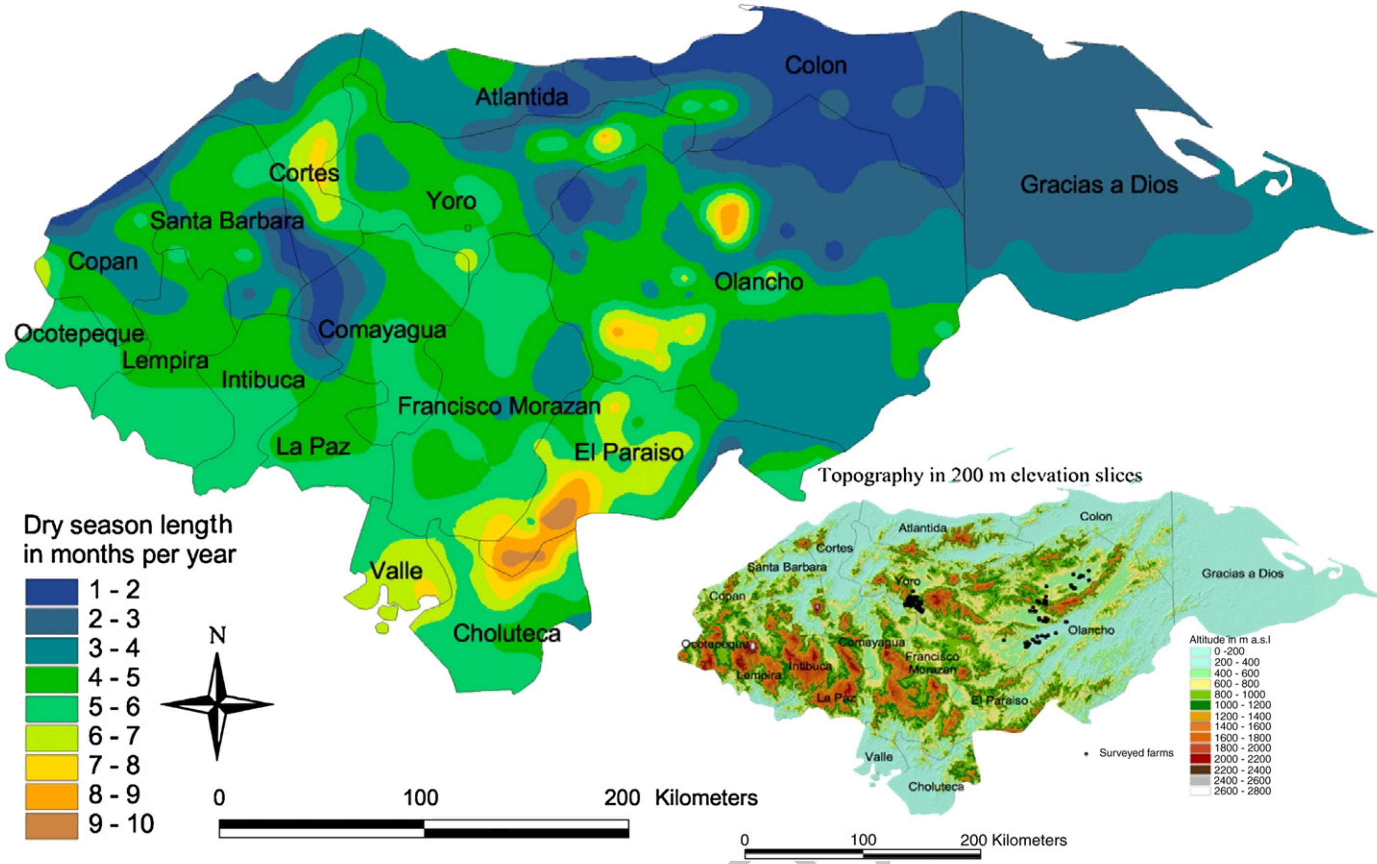

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Fig. 3. Dry season length and topography.

season is short water balance turns negative from February and March on. In most of the country May and June are the first wet months.

3.2. Milk Production for Herd Size Classes

Within each herd size class, there was a wide range of management and general production conditions, like the characteristics of the land, the genetic potential of the cows, the availability of improved forages and the knowledge available on the farm to manage the farm efficiently under the specific circumstances. These differences made it difficult to characterize herd size groups with an indicator, because the indicators always included the range of production conditions of the group. Consequently, indicators on herd size are subject to comparatively high variation within groups (Table 3). This was observed clearly on farms with less than 20 animals. Variability was smaller on farms with more than 20 cattle.

Table 2
Areas and percentage of dry season length classification for Honduras.

Dry season length in months	Area in Square kilometers	Percent of the area
0 to 1	17	0.02
1 to 2	2244	2.00
2 to 3	15189	13.55
3 to 4	24527	21.87
4 to 5	26968	24.05
5 to 6	26836	23.93
6 to 7	11772	10.50
7 to 8	2866	2.56
8 to 9	980	0.87
9 to 10	700	0.62
10 and more	35	0.03

For more detailed presentation of results from on the farming systems see Lentes et al. (2006).

Very small and greater herd sizes differed most in the income/cow/month ($P<0.01$). This was especially striking in the dry season. The farms with few cattle generated the lowest monthly income from milk per cow in both seasons. On very small farms, feed was not available in sufficient quantity and quality and milk production dropped sharply. On some farms, commercial concentrates were used to maintain the cows. Milk production of very small farms was not profitable in the dry season. Only in the wet season farms with 1 to 9 cattle generated positive income from milk but this did not compensate the losses experienced in the dry season.

Small farms generated little income from milk in the dry season but did not loose on average. In the wet season, small farms generated about half the income of the other farm size classes but only slightly more than one third of what positive deviances gained.

The seasonality of income was relevant for all farm sizes (Table 3). Net income from milk per cow on farms with more than 20 cattle dropped between 44% and 53% in the dry season. Dry season incomes per cow were about half the ones in the wet season.

Compared to farms from very small to large, positive deviances showed a high income from milk per cow in both seasons (highest P-value 0.053). Their dry season income was comparable to the wet season income of the farm size classes from 50 cattle upwards. The income of positive deviances dropped by 23% in the dry season.

The productivity of the milk production systems of very small farms was the lowest. They earned more from beef than from milk. Small farms managed to reach a continuous cash flow from their milk production, which exceeded beef production. Yearly income from milk of medium size farms was about 3.9 times higher than income from beef. Among large farms (ranching systems) there were cases that earned much more from beef than from milk. Extra large farms

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Table 3
Income parameters for milk and beef production in herd size classes, Olancho and Yoro in $.

		Very small	Small	Medium	Large	Extra large	Positive deviances
		1 to 9	10 to 19	20 to 49	50 to 99	>100	
		$n=16$	$n=22$	$n=34$	$n=16$	$n=9$	$n=30$
		A	B	C	D	E	F
Dry season: net income from milk/cow/month	Mean	−7.80	3.14	10.12	11.25	11.95	22.83
	Std. Dev.	13.95	20.70	18.60	10.10	7.70	20.62
	Sig.	C**, D***, E***, F***	F**				
Wet season: net income from milk/cow/month	Mean	3.47	10.86	21.68	20.95	21.60	29.91
	Std. Dev.	18.55	21.19	16.01	9.94	7.06	15.82
	Sig.	C**, D**, E**, F***	C*, D*, F***	F*			
Net income from milk/farm/year	Mean	−2.51	528.42	1793.70	3324.82	10134.08	5886.40
	Std. Dev.	457.41	942.48	1649.00	2683.39	5101.11	4967.22
	Sig.	C***, D***, E ***,F***	C**, D***, E***, F ***	D* , E***, F ***	E**, F*	F*	
Net income from beef/farm/year	Mean	87.72	300.63	460.61	5240.96	10375.74	1982.17
	Std. Dev.	136.54	887.60	769.18	11445.17	7733.00	4017.93
	Sig.	D*, E***, F**	E***, F**	E***, F**	E**	F***	

Note: Significance between groups is indicated by letters followed by *$P<0.05$, **$P<0.01$, ***$P<0.001$.

were in equilibrium between the two products, while positive deviances had a clear focus on milk.

3.3. Milk Production for Performance Classes

To characterize farms four performance classes were built, using the indicator net income per cow per month of dry season. Groups differed in the net income/cow/month of dry season ($P<0.01$). The socio-economic and production conditions of performance classes are presented in Table 4.

All farms that experienced losses in the dry season were joined to the class of the very low performers. Even in the wet season, very low performers did only marginally recuperate their expenses. Wet season production cost/liter of milk was very high, compared to the other performance groups ($P<0.001$). Milk production of very low performers was low because few cows of low genetic potential were milked and cost efficient feed was not available in the dry season. The low volumes resulted in an under exploitation of family labor force: Farmers on many very small farms earned less than a worker's salary. While some low performers had negative yearly incomes but were close to the breakeven cost, others lost more.

Dry season production costs of milk declined, as the performance level improved. So did the variability of production costs. Those farms at the bottom of the performance scale lacked of cost efficient farm feed and needed higher milk production volumes to produce efficiently.

Farm size distribution in the performance classes differed significantly ($P<0.005$). Small farms had nearly the same presence in very low and medium performers categories (Table 5). A few small farms performed low (12.7%) and some more performed top (20%). As much as 60% of the top performers were medium size farms, while the number of farms from small to large similar in the medium performer's group.

Low and medium performers generated nearly the same net income/cow during the months of the wet season. Low performers showed deficiencies in dry season herd management such as inadequate provision of feed and exaggerated use of purchased supplements (Lentes et al., 2007). In forage technology adoption, medium performers were ahead of low performers. Medium performers used more low-cost farm feed and were better prepared for the dry season with conserved forage.

Positive deviances lay between medium and top performers in the income but had comparatively high production costs per liter in both seasons. The inclusion of positive deviances in the analysis does not necessarily demonstrate what can be achieved with an appropriate use of forage technology. The analysis rather showed that an integrated change of the livestock production system is not yet fully implemented on these farms. More factors than the availability of forages have influence on the economic success of dairy production e.g. the genetic quality of the milking cows (Lentes et al., 2007).

3.4. Countrywide Income Regionalization

The spatial variables used for regionalization were the length of the dry and wet seasons. For the regionalization of the income indicators, income values for the categories derived from the socio-economic sample were used to create income grid surfaces with GIS. Socio-economic data were collected from areas where the dry season plays an important role and included a wide range of herd management practices. The income surfaces approximate what the income would be if herd composition and management would not differ substantially between those areas and the rest of the country.

3.4.1. Countrywide Income Assessment for Herd Size Classes

The yearly income from milk per dairy cow was mapped for five farm size classes and the category of positive deviances. Table 3 presents the income characteristics of the dairy enterprise for these farm categories.

Table 5 shows the yearly income per cow in relation to dry season length. Very small farms up to 9 cattle head were usually resource poor farms, which did not put much emphasis on dry season milk production. The model designates only areas with dry seasons shorter than 3 months as zones, in which very small livestock herd owners could make profit form milk production (Fig. 4). These areas are

Table 4
Distribution of herd size classes in performance categories.

	Lowest	Low	Medium	Top
	%	%	%	%
Very small	38.71	17.65	3.45	
Small	25.81	11.76	27.59	20.00
Medium	25.81	29.41	31.03	60.00
Large	6.45	23.53	24.14	15.00
Extra large	3.23	17.65	13.79	5.00

Table 5
Income parameters and costs for milk production in performance groups, Olancho and Yoro in $.

		Very low	Low	Medium	Top	Positive deviances
		$n=31$	$n=17$	$n=29$	$n=20$	$n=30$
		A	B	C	D	E
Dry season: net income/cow/month	Mean	−15.31	5.54	14.29	27.08	22.83
	Std. Dev.	11.57	3.41	2.51	5.41	20.62
	Sig.	B***, C***, D***, E***	C***, D***, E**	D***		
Wet season: net income/cow/month	Mean	0.95	19.59	18.57	33.01	29.91
	Std. Dev.	16.22	10.26	9.61	15.24	15.82
	Sig.	B***, C***, D***, E***	D**, E*	D**, E**		
Dry season: milk production cost/liter	Mean	0.53	0.19	0.13	0.09	0.18
	Std. Dev.	0.34	0.07	0.05	0.05	0.06
	Sig.	B***, C***, D***, E***	C**, D***	D*, E**	E***	
Wet season: milk production cost/liter	Mean	0.22	0.07	0.07	0.03	0.10
	Std. Dev.	0.16	0.06	0.05	0.02	0.05
	Sig.	B***, C***, D***, E***	D*, E*	D**, E**	E***	
Net income from milk/farm/year	Mean	−89.39	3699.43	3273.46	3096.26	5886.40
	Std. Dev.	545.69	3961.11	4646.34	1531.33	4967.22
	Sig.	B***, C***, D***, E**	E*	D*, E**	E*	

Note: Significance between groups is indicated by letters followed by *$P<0.05$, **$P<0.01$, ***$P<0.001$.

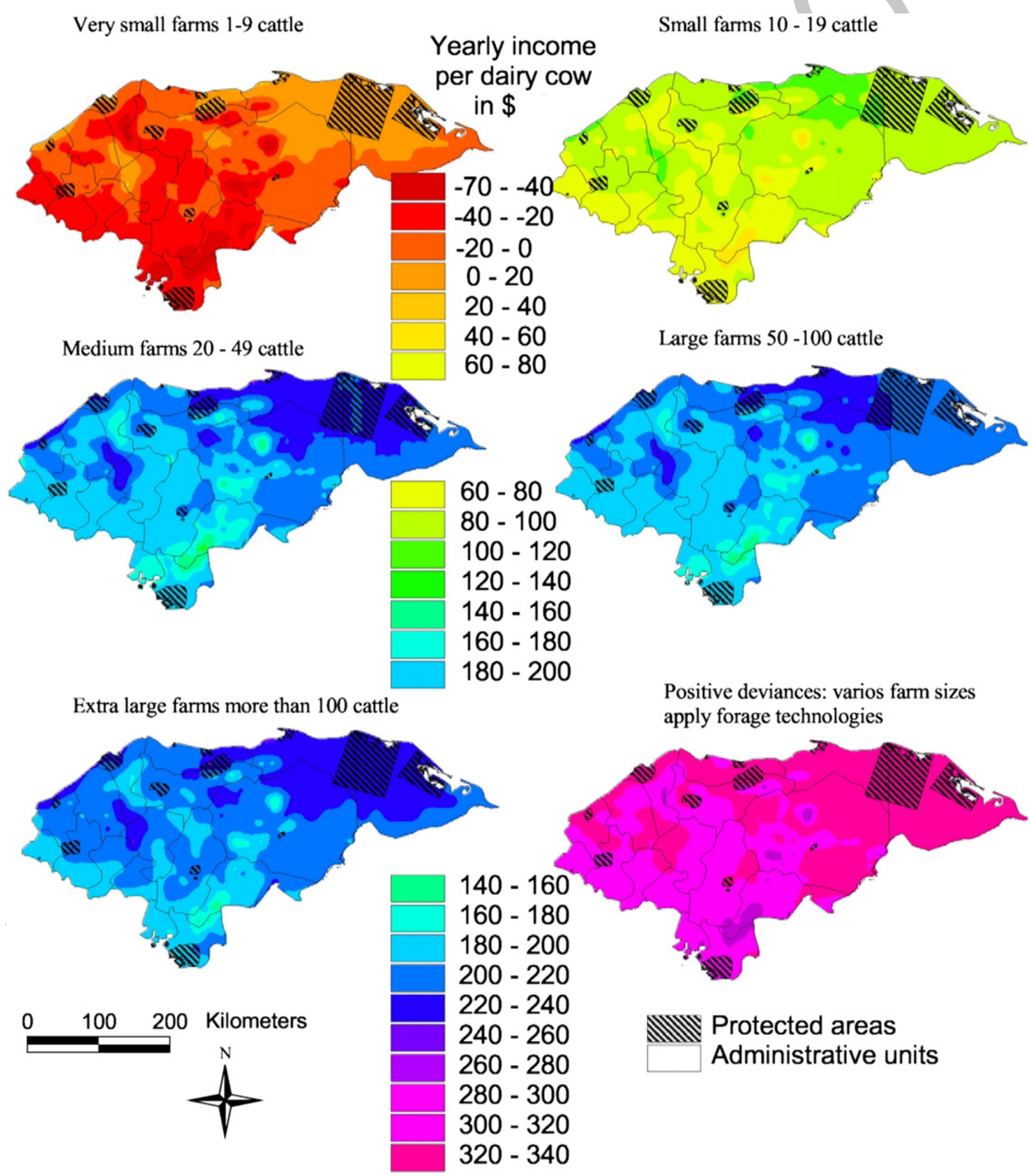

Fig. 4. Yearly income per dairy cow according to dry season length for herd size classes and positive deviances.

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mainly located in the Northern part of the country and in a few mountain areas inside the country. For the drier parts of Honduras, the model estimated losses in milk production for the whole year. Model results of very small farms for all observed dry season lengths differed significantly ($P<0.01$) to the figures for farms with more than 20 heads and positive deviances.

The owners of small herds of 10–19 animals could produce milk profitably in all regions of Honduras (Table 6). Corresponding to dry season lengths small cattle farms earned between 53.13 and 122.61 $/year per cow in milk. Small farms had a lower yearly income from milk/cow than medium farms where dry season was between one and six months long ($P<0.05$). This difference was also observed between small and large farms but only in areas with dry seasons shorter than 4 months ($P<0.05$). Small, medium and large farms differed ($P<0.05$) when dry season was between one and four months. The income difference between small farms and positive deviances was significant for all observed dry season lengths ($P<0.01$).

On those farms with more than 20 cattle, income between the driest and wettest areas varies between 144 and 249$. As in the survey results (Table 3) the model did not state dramatic income differences for those groups with more than 20 cattle. Large and medium size farms differed significantly ($P<0.05$) from positive deviances in most of the observed dry season lengths.

Income depressions in the dry season are great on very small and small farms. It is apparent, that a better dry season herd management would help farms to generate more income per cow. Very small farms would need to improve their dry season feed base and increase the number of milking cows to be able to work profitably in areas with more than 3 months of dry season. When compared to the average Honduran farmer of different herd sizes below 100, positive deviances yield the highest incomes per cow per year in the whole country.

3.4.2. Countrywide Income Regionalization for Performance Classes

In the countrywide maps (Fig. 5) on the income/cow/year for performance classes, income is a function of dry season length and the dry and wet season incomes for each performance class (Table 7). The degree to which yearly income depends on the dry season length differs between the performance groups and is determined by the difference in incomes between the dry and the wet season.

The maps show, that there is only a small area mapped in Honduras, where very low performers are predicted to recuperate costs of milk production. Taking into account that the dry season length estimation could not validated through measurements for the wettest and driest parts of the country, the minimum and maximum values from the grid statistics should only be seen as approximations. However wettest and driest areas cover comparatively small areas.

Although the income of low performers traces the spatial pattern of dry season length in Honduras, their income is always positive and lower than the incomes of top performers and positive deviances ($P<0.01$). The maps (Fig. 5) and Table 7 show that the income range between areas with short and long dry season is the highest in the very low and low performers categories. Low and medium performers differed in areas with more than six dry months ($P<0.05$).

Medium and top performers were considerably less affected by dry season length. These groups generated comparatively high incomes in all areas of Honduras. Under all climatic conditions, the income of medium performers was lower than of top performers ($P<0.001$). Top performers and positive deviances had similar incomes under all climatic conditions. Top performers showed differences to the other performance groups in all climate scenarios ($P<0.05$). The differences between positive deviances and medium performers lost strength for dry seasons of eight ($P=0.052$), nine ($P=0.069$) and ten months ($P<0.081$).

Table 6
Income from milk/cow/year of herd size classes for observed dry season lengths.

	Very small	Small	Medium	Large	Extra large >	Positive deviances
	1 to 9	10 to 19	20 to 49	50 to 99	100	
	$n=16$	$n=22$	$n=34$	$n=16$	$n=9$	$n=30$
	A	B	C	D	E	F
1 dry month	30.35	122.61	248.63	241.71	249.56	351.83
	213.78	249.60	188.73	114.19	83.14	187.18
	C**, D**, E**, F***	C*, D*, F***	F*	F*		
2 dry months	19.08	114.89	237.06	232.01	239.91	344.75
	205.51	245.66	186.45	109.86	81.94	186.03
	C**, D**, E**, F***	C*, D*, F***	F*	F*		
3 dry months	7.82	107.17	225.49	222.30	230.27	337.67
	197.84	242.43	185.30	106.41	81.14	186.39
	C**, D***, E**, F***	C*, D*, F***	F*	F*		
4 dry months	−3.45	99.45	213.93	212.60	220.62	330.58
	190.83	239.96	185.30	103.93	80.77	188.25
	C**, D***, E***, F***	C*, D*, F***	F*	F*		
5 dry months	−14.71	91.73	202.36	202.89	210.97	323.50
	184.57	238.25	186.46	102.48	80.82	191.56
	C**, D***, E***, F***	C*, F***	F*			
6 dry months	−25.98	84.01	190.79	193.19	201.32	316.42
	179.13	237.33	188.75	102.12	81.31	196.24
	C**, D***, E***, F***	C*, F**	F*	F*		
7 dry months	−37.24	76.29	179.22	183.49	191.68	309.34
	174.58	237.21	192.14	102.85	82.21	202.21
	C***, D***, E***, F***	F**	F*	F*		
8 dry months	−48.51	68.57	167.66	173.78	182.03	302.25
	171.01	237.89	196.56	104.65	83.51	209.35
	C***, D***, E***, F***	F**	F*			
9 dry months	−59.77	60.85	156.09	164.08	172.38	295.17
	168.47	239.36	201.95	107.46	85.21	217.55
	C**, D***, E***, F***	F**	F*	F*		
10 dry months	−71.04	53.13	144.52	154.37	162.73	288.09
	167.01	241.61	208.24	111.22	87.27	226.70
	C**, D***, E***, F***	F**	F*			

Note: Significance between groups is indicated by letters followed by *$P<0.05$, **$P<0.01$, ***$P<0.001$.

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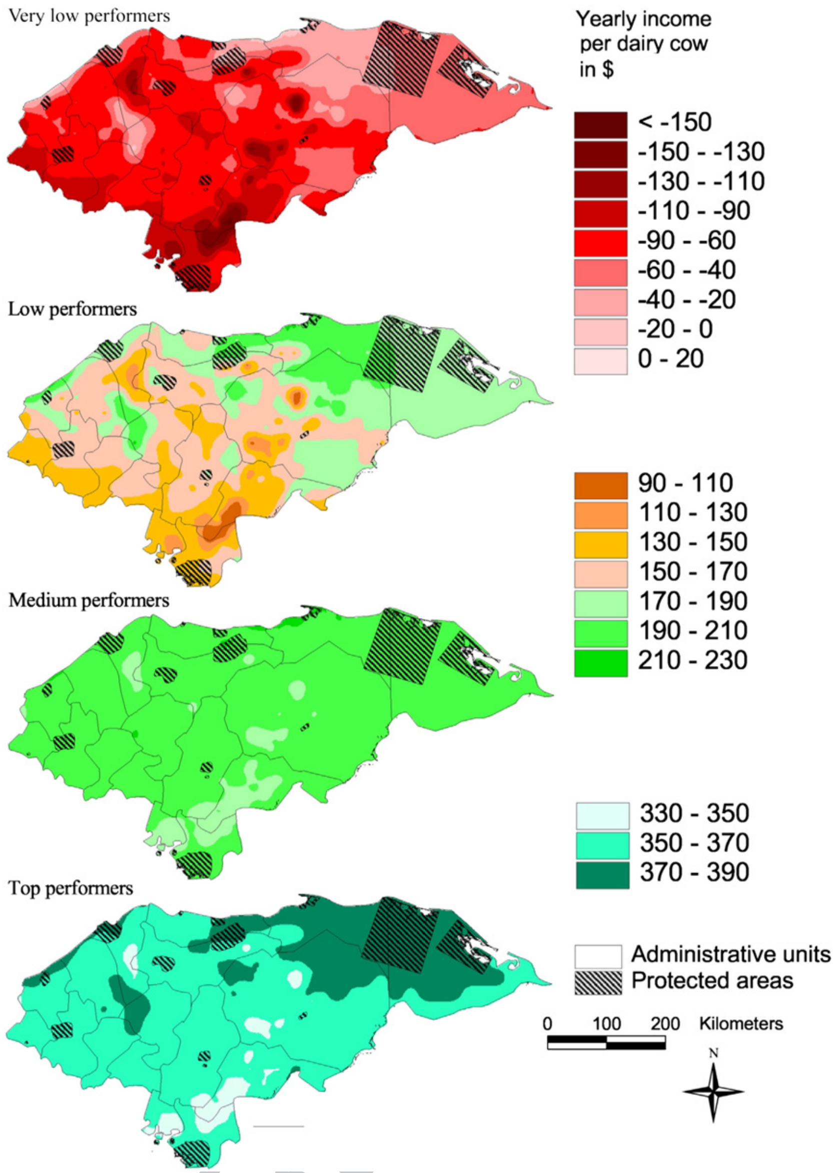

Fig. 5. Yearly income per dairy cow according to dry season length for performance group.

Using the average values of income per farm, the regionalization of income parameters according to climate yields the equations:

$$\text{Very low performers}: Y = 11.4 - 16.26x \quad (10)$$

$$\text{Low performers}: Y = 235.08 - 14.05x \quad (11)$$

$$\text{Medium performers}: Y = 228.84 - 4.28x \quad (12)$$

$$\text{Top performers}: Y = 396.120 - 5.93x \quad (13)$$

$$\text{Positive deviances}: Y = 358.909 - 7.079x \quad (14)$$

where:

Y net income/cow/year
x months of dry season.

The income gradients, as shown in Eqs. (10) and (11) of very low and low performers are considerably steeper than for the other performance classes. This means, that these two classes are affected more seriously by dry season length than the others. This can also be seen from the income range between the wettest and driest parts of the country on Fig. 6.

Low and medium performers would generate nearly the same income under conditions without dry season constraints (Eqs. (11) and (12)). For each month of dry season, the gradient of low performers was nearly 10 $ steeper than the one of the medium performers. Medium performers income per cow declined 4.28 $ for each month of dry season (Eq. (12)). If there were no dry season, top performers would have the highest income. In the conditions with dry season, the decline of the income per dairy cow per month of dry season was a little steeper than among medium performers. Positive deviances showed comparatively higher costs during the dry season than top performers. Their yearly income/cow declined more rapid/steeply for each month of dry season (Eq. (14)).

3.4.3. Average Income Assessment for Farm Size Class Proportions for Each Department

According to SECPLAN (1994), the distribution of herd size classes was uneven throughout the country (Fig. 6). The Western and Southern departments had a high share of farms with very small herd sizes of less than 10 cattle. The maximum share of very small herds

Table 7
Income from milk/cow/year of performance classes for observed dry season lengths.

		Lowest	Low	Medium	Top	Positive deviances
		$n=31$	$n=17$	$n=29$	$n=20$	$n=30$
		A	B	C	D	E
1 dry month	Mean	−4.84	221.02	218.54	390.24	351.83
	St. Dev	185.01	113.78	106.03	170.45	187.18
	Sig	B***, C***, D***, E***	D**, E**	D***, E**		
2 dry months	Mean	−21.10	206.98	214.26	384.31	337.67
	St. Dev	175.99	104.54	96.86	158.11	186.03
	Sig	B***, C***, D***, E***	D**, E**	D***, E**		
3 dry months	Mean	−37.35	192.93	209.99	378.37	337.67
	St. Dev	167.62	95.45	87.79	145.96	186.39
	Sig	B***, C***, D***, E***	D**, E**	D***, E**		
4 dry months	Mean	−53.61	178.88	205.71	372.44	330.58
	St. Dev	160.00	86.55	78.84	134.05	188.25
	Sig	B***, C***, D***, E***	D***, E**	D***, E**		
5 dry months	Mean	−69.87	164.83	201.43	366.51	323.50
	St. Dev	153.24	77.90	70.05	122.45	191.56
	Sig	B***, C***, D***, E***	D***, E***	D***, E**		
6 dry months	Mean	−86.12	150.79	197.16	360.57	316.42
	St. Dev	147.46	69.61	61.51	111.25	196.24
	Sig	B***, C***, D***, E***	C*, D***, E***	D***, E*		
7 dry months	Mean	−102.38	136.74	192.88	354.64	309.34
	St. Dev	142.78	61.81	53.33	100.59	202.21
	Sig	B***, C***, D***, E***	C**, D***, E***	D***, E*		
8 dry months	Mean	−118.64	122.69	188.60	348.70	302.25
	St. Dev	139.31	54.71	45.70	90.66	209.35
	Sig	B***, C***, D***, E***	C***, D***, E**	D***		
9 dry months	Mean	−134.89	108.65	184.33	342.77	295.17
	St. Dev	137.15	48.64	38.94	81.73	217.55
	Sig	B***, C***, D***, E***	C***, D***, E***	D***		
10 dry months	Mean	−151.15	94.60	180.05	336.83	288.09
	St. Dev	136.35	44.00	33.59	74.15	226.70
	Sig	B***, C***, D***, E***	C***, D***, E**	D***		

Note: Significance between groups is indicated by letters followed by *$P<0.05$, **$P<0.01$, ***$P<0.001$.

was found in Intibuca with 81% of the farms. On country average the majority of cattle farms had very small herds. These were the farms that were affected most by a prolonged dry season and which were least developed in forage options.

The average income per cow per department was dependent on the herd size composition given for each department. As it was shown in Table 3 and Fig. 4, each herd size class had distinct incomes from milk for the dry and wet seasons.

The corresponding average distribution of these classes in each department and their respective values for the indicator income per cow in the dry and wet season were used to calculate the average yearly performance of the dairy enterprises per department. This regionalization approach was suitable to compare the profitability of milk production in departments. Based on the presence of cattle herd sizes, the income per cow of the average farm in this department was calculated and the dry season length was considered.

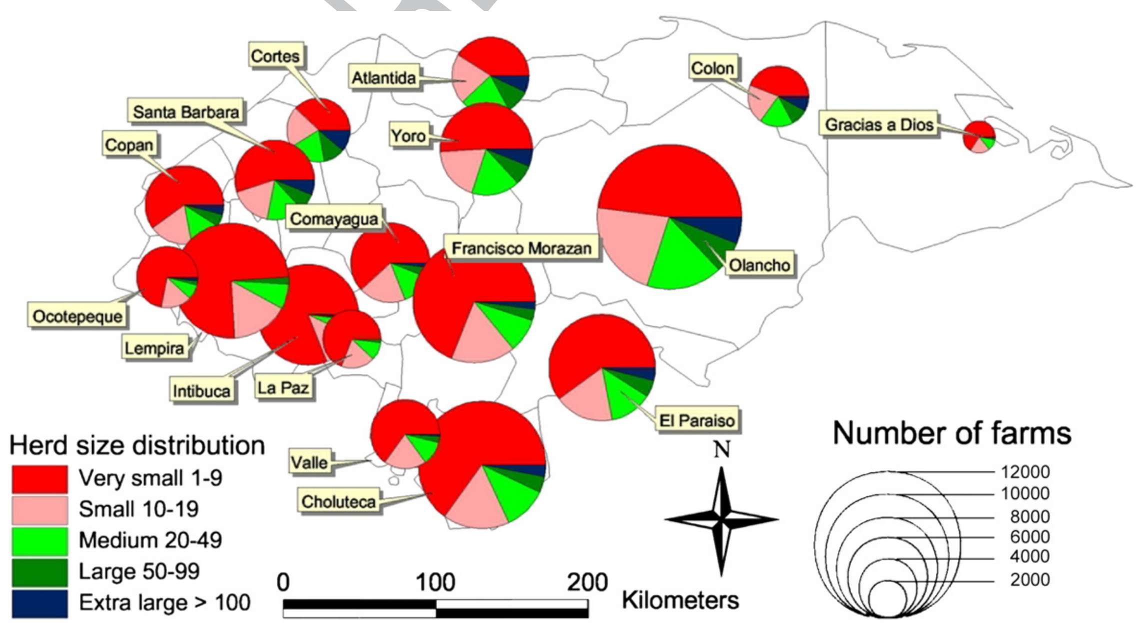

Fig. 6. Cattle herd size distribution in departments for 1993.

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As it can be read from Fig. 7, the central part of Honduras showed incomes between 20 and 40$ in the areas with 4 to 5 months of dry season, but dropped to 0 to 20$/cow/year in much of the Northern part of Francisco Morazán. For most of the mountainous areas of e.g. Olancho and Yoro, which had between 3 and 6 months of dry season, the model estimations were between 20 to 80$/cow/year. In the North along the Caribbean or in the east of Olancho, incomes per cow rose to values between 80 and 120$/cow/year, while in small areas income may reach up to 130$. Although Gracias a Dios is one of the areas with most rainfall in Honduras, the income level of livestock keepers was estimated low, because of a very high share of very small farms in the population.

4. Discussion and Conclusions

Dry season length was calculated from evapotranspiration generated with the method of Thornthwaite (1948). The weather simulation software, MarkSim (Jones, 2001) provided the temperature and rainfall input data. Temperatures were corrected with station data. The resolution of the dry season assessment is one month. Experienced local experts agreed with the final dry season map produced, although it tends to over and undershoot in extreme conditions, like in the wettest and driest parts of Honduras, which cover comparatively small areas (less than 4% of the area).

With the income regionalization maps we localized gradual changes from low to high income for herd size and performance classes on country scale. Model results showed clear impacts of the dry season length on the income per cow per year.

When based on herd size classes, income indicators had the inevitable disadvantage of comparatively high standard deviations (Table 3). The standard deviations represent a measure for the representativeness of mean values (Bamberg and Baur, 2002). It showed that within each herd size class, there were farms with higher and lower incomes, as compared to the mean. The reason why the classification in herd size classes was used despite the high variability of the indicator was that herd size can be easily assessed in the field and is easily understood by farmers, extension workers and policy makers. Income from milk per cow per year of extra large farms was similar to the values for positive deviances under all climatic conditions. However positive deviances had higher income per cow than farms with less than 100 cattle where dry season was up to seven months long ($P<0.05$). These conditions covered 96% of Honduras. Medium size farms earned more than small farms where dry season was six months and shorter (85% of Honduras). Small and very small farms were the most hit by a long dry season.

The classification on performance yielded more representative mean values and was more precise for regionalization. Performance indicators are beneficial tools for assisting effective decision making aimed at improving business performance (Wilson et al., 2005). The disadvantage of the performance indicator used was that it was not as quickly accessible in the field when compared to herd size.

Dry season impact on income for low performers was greater than for medium performers where the dry season length exceeded six months ($P<0.05$), i.e. on 16.5% of the territory of Honduras. Very low, low and medium performers had lower incomes than top performers under all observed dry season lengths ($P<0.01$). On 96% of the area of Honduras (up to 7 months of dry season), medium low and very low performers had lower incomes than positive deviances ($P<0.05$).

For the regionalization of average income/cow/year per department, the paper made use of the available data and demonstrated the methodology, estimating total livestock population for 2005 from annual growth rates in the post-Mitch period. Since the agricultural census data (SECPLAN, 1994) were old it would make sense to apply the method again once a new census becomes available. When the average herd size composition of departments was considered, regions with a high share of small herd sizes showed low incomes per cow.

The regionalization of positive deviances (in Fig. 5) showed the state of farms that were developing towards more intensive cattle management and better use of forages. Sharp dry season income drops (44–53%), as observed on farms with more than 20 cattle could be avoided with a better use of forage technologies and intensification. The even sharper income drops on farms with less than 20 cattle could be mitigated through adequate low-cost measures that need to be based on as much as possible farm produced feed. One recommendation is the subsidized introduction of well-adapted improved grasses (e.g. *B. brizantha cv* Toledo) and their conservation.

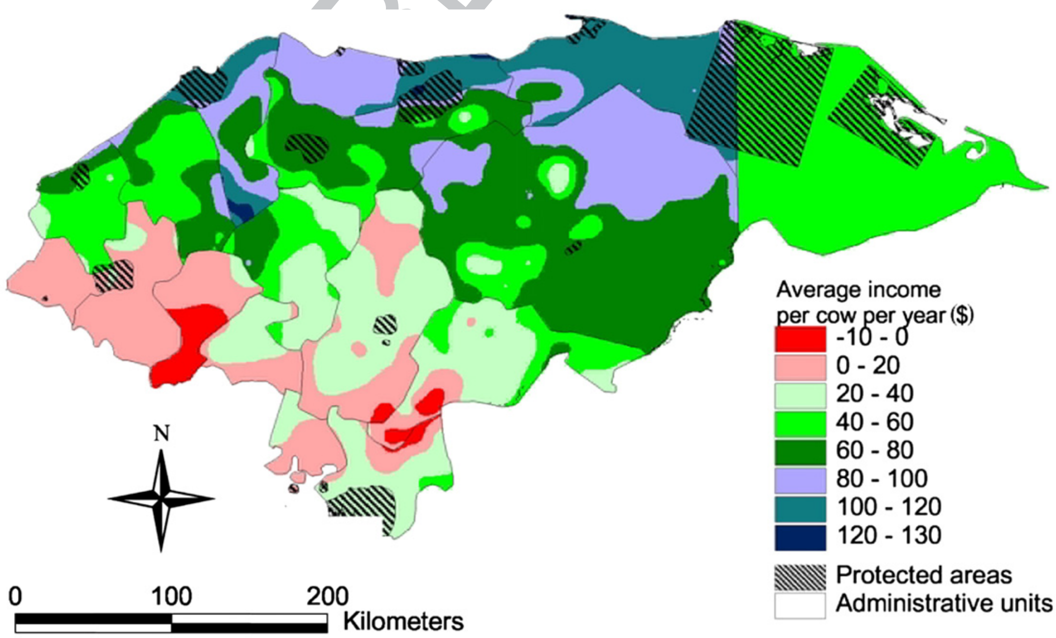

Fig. 7. Income distribution derived for departments for 2005.

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Another possibility would be the improvement of maize stover with *Lablab purpureus* as a legume (Lentes et al., 2007).

Interpreting the maps on the performance classes as stages of intensification, it can be demonstrated to farmers and policy makers how much and where in Honduras an upward movement between performance classes is likely to increase income per cow. Intensification of production is an important solution for resource-poor farmers (Peters et al., 2001) and for a self-sufficient milk production in Honduras.

The adoption of new crops and improved technologies is constrained substantially where the availability of working capital is limited (Van Keulen, 2007). Financial bottlenecks are important constraints for adoption of forage technologies and genetic improvements of the herds on small and very small farms. These farms lack of capital at the end of the dry season and their priority is to secure subsistence crop production. Without an increase of working capital it is unlikely that resource poor farms in such a situation invest in forages of better nutritive value and their conservation during the rainy season, because their crop production requires the investment. Without investments or efforts for intensification, these farms will remain on low-income levels. More off-farm employment would help alleviate the lack of capital since the additional income could be invested in more capital-intensive technologies (Van Keulen, 2007). Such opportunities are rare and usually far from being available to the rural poor in Honduras. Nevertheless some innovative and motivated individuals undertook low-cost efforts and improve slowly.

On farms with more than 20 head of cattle, the probability for change was higher. These farms are able to accumulate some capital to reinvest in the farm e.g. in forages, their conservation or in cow breeds with better genetic potential for milk production.

The resource use efficiency of farms was related to the length of the dry season and the technological level of the farms. Where the dry season was very long, farmers with low technological level generated little to reinvest and were thus cash constrained. A higher level of dry season adaptation was required to sustain production and income with increasing dry season length.

The climatic data used for this paper are estimations for long-term averages derived from the past. It is however known (e.g. from farmers experience and a few climate stations, where measurements are done) that precipitation and temperatures and also dry season length is variable between years. Long-term climate change scenarios for Honduras show trends of increasing temperatures and decreasing precipitation (IPCC, 2007). In the decadal climate risk index for 1998–2007 of Harmeling (2008), Honduras is listed as the most vulnerable country, followed by Bangladesh and Nicaragua. Taking these factors into account, the maps produced in this paper can also be interpreted as vulnerability maps for climate change and natural disasters. Those farmers that are already seriously affected under average dry season conditions are more vulnerable to climate change and natural disasters. Those farmers that are more efficient under average climatic conditions are more resilient to the effects of natural disasters and climate change.

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References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration — Guidelines for computing crop water requirements — FAO Irrigation and drainage paper No. 56. Food and Agriculture Organization of the United Nations (FAO), Rome.

Argel, P., 1999. Caracterización de sitios con potencial de adopción de germoplasma forrajero mejorado por pequeños y medianos productores de doble propósito en Honduras. Informe de Consultoría. Centro Internacional de Agricultura Tropical (CIAT), Cali.

Bamberg, G., Baur, F., 2002. Statistik. Oldenbourgs Lehr- und Handbücher der Wirtschafts- und Sozialwissenschaften. Oldenbourg, Munich.

Biggs, S., 2008. Learning from the positive to reduce rural poverty and increase social justice: institutional innovations in agricultural and natural resources research and development. Experimental Agriculture 44, 37–60.

Boeringa, M., 2000. Nieuwland Kriging Interpolator, Plugin for ArcView GIS. [3.2]. Nieuwland Automatisering, Wageningen.

Camargo, A.P., Marin, F.R., Sentelhas, P.C., Picini, A.G., 1999. Adjust of the Thornthwaite's method to estimate the potential evapotranspiration for arid and superhumid climates, based on daily temperature amplitude. Revista Brasileira de Agrometeorologia 7 (2), 251–257 in Portuguese with English summary.

CGIAR-CSI (CGIAR — Consortium for Spatial Information), 2004. SRTM 90m Digital Elevation Data. http://strm.csi.cgiar.org/ accessed on 30 January 2009.

CGIAR-CSI (CGIAR — Consortium for Spatial Information), 2006. CRU TS 2.1 Climate Database. http://cru.csi.cgiar.org/ accessed on 30 January 2009.

Delgado, C.L., 2005. Rising demand for meat and milk in developing countries: implications for grassland-based livestock production. Pp. 29–39. In: McGilloway, D.A. (Ed.), Grassland — A Global Resource. Wageningen Academic Publishers.

FAO, 2005. FAO statistical country profile Honduras. — From FAO statistics division. http://www.fao.org/es/ess/yearbook/vol_1_2/pdf/Honduras.pdf accessed on 30 January 2009.

Fujisaka, S., Holmann, F., Peters, M., Schmidt, A., White, D., Burgos, C., Ordoñez, J.C., Mena, M., Posas, M.I., Cruz, H., Davis, C., Hincapié, B., 2005. Estrategias para minimizar la escasez de forrajes en zonas con sequías prolongadas: Honduras y Nicaragua. Documento de Trabajo No. 201. CIAT (Centro Internacional de Agricultura Tropical), Cali.

Harmeling, S., 2008. Global Climate Risk Index (CRI) 2009 — how extreme weather events affect countries. Presentation held at COP14, Poznan, 4th December, 2008. http://www.germanwatch.org/klima/cri09pres.pdf accessed on 30 January 2009.

Holmann, F., 2001. Milk market of small scale artisan cheese factories in selected livestock watersheds of Honduras and Nicaragua. Livestock Research for Rural Development 13, 1. http://lrrd.org/lrrd13/1/hilm131.htm accessed on 30 January 2009.

INE (Instituto Nacional de Estadistica), 2001. Encuesta Agricola Nacional 2000–2001, Tomo III, Ganadería y Otras Especies Animales. Secretaria del Estado del Despacho Presidencial, Tegucigalpa, Republica de Honduras.

IPCC, 2007. Summary for policymakers. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Jansen, H.G.P., Pender, J., Damon, A., Schipper, R., 2006. Rural development policies and sustainable land use in the hillside areas of Honduras. A Quantitative Livelihoods Approach. Research report No. 14. International Food Policy Research Institute (IFPRI), Washington, DC.

Jones, P., 2001. A Computer Tool that Generates Simulated Weather Data for Crop Modeling and Risk Assessment. http://gisweb.ciat.cgiar.org/marksim/index.htm accessed on 30 January 2009.

Kyeyamwa, H., Speelman, S., van Huylenbroeck, G., Opuda-Asibo, J., Verbeke, W., 2008. Raising offtake from cattle grazed on natural rangelands in sub-Saharan Africa: a transaction cost economics approach. Agricultural Economics 39 (1), 63–72.

Lentes, P., 2004. The Contribution of GIS and Remote Sensing in Micro-economic and Regional Farming Systems Research in North Western Vietnam. Farming and Rural Systems Economics, Vol. 52. Margraf Verlag, Weikersheim.

Lentes, P., 2006. Spatial analyses and impact assessment for rural livelihood in mountain regions of Northern Vietnam. In: Doppler, W., Weber, E. (Eds.), Resources and Livelihood in Mountain Areas of South East Asia. Farming and Rural Systems in a changing environment. Margraf Publishers, Weikersheim, pp. 377–409.

Lentes, P., Peters, M., White, D., Holmann, F., Reiber, C., 2006. Assessing and comparing income generation of livestock holders in Olancho, Honduras. An Analysis Across Typical Landscapes and Farming System. Tropentag 2006, Prosperity and Poverty in a Globalized World — Challenges for Agricultural Research October 11–13, 2006. University of Bonn, Bonn, Germany, p. 144.

Lentes, P., Holmann, F., Peters, M., White, D., Cruz, H., 2007. Management and farm characteristics that favor or impede efficient resource use in dual-purpose cattle systems in Central America. In: Lascano, C. (Ed.), Tropical Grasses and Legumes: optimizing genetic diversity for multipurpose use (Project IP5). Annual Report 2006. Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, pp. 170–186. http://www.ciat/cgiar.org/forrajes/pdf/report_2006/output_4.pdf accessed on 30 January 2009.

Matheron, G., 1963. Principle of geostatistics. Economic Geology 58, 1246–1266.

Mitchell, T.D., Jones, P.D., 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25, 693–712.

Munroe, D.K., Southworth, J.Tucker, Tucker, C.M., 2002. The dynamics of land-cover change in western Honduras: exploring spatial and temporal complexity. Agricultural Economics 27 (3), 355–369.

Pelton, W.L., King, K.M., Tanner, C.B., 1960. An evaluation of the Thornthwaite and mean temperature methods for determining potential evapotranspiration. Agronomy Journal 52, 387–395.

Pereira, A.R., Pruitt, W.O., 2004. Adaptation of the Thornthwaite scheme for estimating daily reference evapotranspiration. Agricultural Water Management 66 (3), 251–257.

Peters, M., Horne, P., Schmidt, A., Holmann, F., Kerridge, P.C., Tarawali, S.A., Schultze-Kraft, R., Lascano, C.E., Argel, P., Stür, W., Fujisaka, S., Müller-Sämann, K., Wortmann, C., 2001. The role of forages in reducing poverty and degradation of natural resources in tropical production systems. ODI Agricultural Research and Extension Network, Network Paper No. 117.

Schöninger, M., Dietrich, J., 2003. Hydroskript. http://www.hydroskript.de. accessed on 30 January 2009.

SECPLAN (Secretaría de Planificación, Coordinación y Presupuesto), 1994. IV Censo Nacional Agropecuario 1993. Tomo V, Ganadería y otras especies animales. Tegucigalpa, Graficentro. Censo Agropecuario 1993.

SERNA, 2005. Informe del Estado y Perspectivas del Ambiente: Geo Honduras 2005/Honduras, Secretaría de Recursos Naturales y Ambiente (SERNA)1a. ed. Programa de las Naciones Unidas para el Medio Ambiente (PNUMA)/(SCANCOLOR), Tegucigalpa. 172 pp.

SERNA, 2007a. Monthly rainfall sums in mm. Stations: La Unión (1981–2005), La Suncuya (1983–2006), El Rosario (1980–2006), La Conce (1982–2007), Guinope (1966–2007), Taupasenti (1968–2006), Guajinquil (1987–2007), San Lucas (1966–2007), Texiguat (1967–2006), Villa Ahumada (1975–2006), Oropoli (1972–2007), Potrerillos (1966–2007), Mariata (1966–2007), Guayabillas (1967–2006): Secretaria de Recursos Naturales, Dirección General de Recursos Hídricos, Departamento de Servicios Hidrológicos y Climatológicos, Tegucigalpa, Honduras.

SERNA, 2007b. Monthly mean Temperatures in °C . Stations: La E.N.A Catacamas (1991–2006), La Conce (1982–2006), Villa Ahumada (1975–2006), Guayabillas (1967–2006), Secretaria de Recursos Naturales, Dirección General de Recursos Hídricos. Departamento de Servicios Hidrológicos y Climatológicos, Tegucigalpa, Honduras.

SMN (Servicio Meteorológico Nacional), 2007. Monthly mean Temperatures in °C and monthly rainfall sums in mm. Years 1995–2006. Stations: Catacamas, Yoro, La Esperanza, Jacaleapa. SMN, Departamento de Climatología, Tegucigalpa, Honduras.

Stanhill, G., 1961. A comparison of methods of calculating evapotranspiration from climatic data. Israel Journal of Agricultural Research 11, 159–171.

Suttie, J.M., 2000. Hay and straw conservation. For small-scale farming and pastoral conditions. (FAO Plant Production and Protection Series No. 29, Rome, Italy).

Thornthwaite, C.W., 1948. An approach toward a rational classification of climate. Geographical Review 38 (1), 55–94.

van Keulen, H., 2007. Quantitative analyses of natural resource management options at different scales. Agricultural Systems 94, 768–783.

Williams, R.G., 1986. Export Agriculture and the Crisis in Central America. The University of North Carolina Press, Chapel Hill.

Wilson, R.H., Charry, A.A., Kemp, D.R., 2005. Performance indicators and benchmarking in Australian agriculture: synthesis and perspectives. Extension Farming Systems, 1,1 — Research Forum. http://www.csu.edu.au/faculty/science/saws/afbmnetwork/efsjournal/volume1/number1/EFS_Journal_v01_n05_RossWilson_et_al.pdf accessed on 30 January 2009.

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