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Vol. 9(18), pp. 1396-1406, 1 May, 2014
DOI: 10.5897/AJAR2013.8121
Article Number: FA38E5844409
ISSN 1991-637X
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African Journal of Agricultural Research

Full Length Research Paper

Impact of climate change on grasses cultivation potential of three altitudinal strata-agricultural lands of Mexico

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Received 24 October, 2013; Accepted 7 April, 2014

This study estimated the impact of climate change in the period 2040-2069 on six grasses potential areas in three altitudinal zones of México: 0 to1200 m (lowlands), 1200 to 2200 m (midlands) and >2200 m (highlands). Topography, soil and climate variables were used to depict potential areas. Climate data for 1961-1990 (reference climatology) and 2040-2069 were obtained from the WorldClim Earth System Grid Portal and were worked in 2.5 arc minutes raster images in the Idrisi Selva System. For the 2040-2069 climatology, three GCMs were considered: MPIM-ECHAM5, MIROC3.2 (medres) and UKMO_HADCM3, under A2 emissions scenario. The results showed that most of the potential areas with optimal conditions for grasses will remain in lowlands, however the surface with these conditions will tend to decrease for *Cenchrus ciliaris, Andropogon gayanus and Brachiaria mutica* at a rate of 35-49%, 2-63% and 15-30%, respectively, which will affect mostly to *C. ciliaris,* since it will tend to migrate to midlands. Optimal conditions surface for *C. gayana* and *C. dactylon* will not change in lowlands, but will increase in midlands 63-103% and 74-90%, respectively. For *H. rufa*, the optimum conditions surface will rise 5-17% in lowlands and 391-449% in midlands. In highlands, potential areas for grasses were estimated majorly as suboptimal, however with climate change *C. ciliaris, C. gayana* and *C. dactylon* will increase their optimal conditions surface in highlands. For *A. gayanus, B. mutica* and *H. rufa* no optimal conditions surface was determined in highlands neither in the reference climatology nor in the future climatologies.

Key words: Climate change and forage grasses; Climate change and altitudinal zones; Tropical and subtropical grasses.

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), CO_2 concentrations in the atmosphere, in preindustrial times were of 600 gigatons (Gt); concentrations currently are of 800 Gt and the expected increment in CO_2 atmosphere would be closer to 1,000 Gt by 2050 (IPCC, 2007). The increment in atmospheric concentrations of CO_2, as well as other greenhouse effect gases (GHGs), due to intensification of anthropogenic

activities (Hegerl et al., 2007), is associated to the change of temperature patterns and precipitation, which will cause important effects on development and on global agricultural productivity (Attipalli et al., 2010; Deryng et al., 2011; Hsiang et al., 2011), as the soil water availability is manifested according to complex interactions between these two factors (Wang , 2005).

Numerous studies indicate that plants present a positive response to increased CO_2; which is manifested through the increment in photosynthesis, biomass and production of crops (Kimball et al., 2002; Tubiello et al., 2007). The capture of atmospheric CO_2 by photosynthesis, is crucial for the production of food, fiber and fuel for humanity (Friend et al., 2009). It has been estimated that when increasing at twice the average of CO_2 content, economic performance is increased about 10% in C_4 specie (Hatfield et al., 2011; Izaurralde et al., 2011) and up to 20% in high radiation conditions (Ghannoum et al., 2000); however, little is known about the interactive effects of environmental variables, nutrients, water availability and high CO_2 increment during the growth of C_4 plants (Leakey et al., 2009).

Moreover, as a result of increment in greenhouse gases on the atmosphere, an increment in temperature is produced, which is unambiguous (Trenberth et al., 2007); and therefore drying of many regions through increased evaporation is induced (Wang, 2005; Woodhouse et al., 2010), while the maturity crop process is accelerated, reducing leaf area duration and thus the total water requirement of crop maturity (Hatfield et al., 2011; Ojeda et al., 2011).These changes in climatic patterns, will cause profound effects on terrestrial plant growth and productivity in the near future (Attipalli et al., 2010), and, defining the geographical potential distribution on yield losses of crops, is transcendental as well as to develop mitigation strategies (Deryng et al., 2011; Justin et al., 2012).

Moreover, numerous studies indicate that agriculture must meet the dual challenge of feeding a growing population and a high demand for diets rich in meat and calories, while minimizing environmental impacts (Verena et al., 2012). In Mexico, there are studies about climate change and its impact on crop production, but few have analyzed in detail the effects of this phenomenon on forage species in particular. The country is characterized by an ample altitudinal variation (0 to 5747 m), which impose diverse c limatic conditions for agriculture. With the presence of climate change it is visualized that a re-accommodation of crops will take place as temperatures continue increasing and migration to higher altitudes is expected. Nowadays is necessary to depict how the climate conditions will be in the mean future in order to planning agriculture. This is why the objective of this study was to determine the impact of climate change on potential areas of six tropical grasses in Mexico as a function of altitudinal strata.

MATERIALS AND METHODS

The study was conducted in agricultural areas of Mexico, which were studied under the following altitudinal strata: lowlands (< 1200 masl), midzones (1200 to 2200 masl) and highlands(> 2200 masl) .

Species studied

Six forage species were included: *Andropogon gavanus* Kunth, *Brachiaria mutica* (Forssk.) Stapf, *Cenchrus ciliaris* L., *Chloris gayana* Kunth, *Cynodon dactylon* (L.) Pers., and *Hyparrhenia rufa* Nees; species of great interest for their productive potential in Mexico.

Databases and information systems

Monthly and annual data of precipitation, maximum temperature, minimum temperature and average temperature were used, from the 1961 to 1990 period (reference climatology) and from 2040 to 2069 period, to determine potential areas of the grasses under study. These climate data were obtained from the data portal of Earth System Grid (ESG) in WorldClim and were managed by raster images with a resolution of 2.5 minutes of arc, at the Idrisi Selva System (Eastman, 2012). For the 2040 to 2069 period, GCMs MPIM- ECHAM5, MIROC3.2 (medres) and UKMO_HADCM3 were considered under A2 greenhouse gas emissions scenario (IPCC, 2007). These three models have showed good fitting to Mexico environmental conditions and have been employed frequently to simulate future climatic conditions (Conde et al., 2006). To determine potential areas, other diagnostic variables were also included, such as agricultural land use, soil slope, soil texture and soil depth; which were obtained from the Environmental Information System (SIAN) of the Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias in Mexico (Díaz et al., 2012), except for agricultural land use and texture, which were extracted from the image of the soil usage series III of Instituto Nacional de Estadística, Geografía e Informática in Mexico (INEGI, 2009).

Statistical analysis

Kolmogorov-Smirnov test was used to check normality on the data series of precipitation and temperature (1961 to 1990 climatology) in the three altitudinal zones. The test was run through SPSS Statistics 19 software (IBM Corp, 2010).

Since the test of normality reported in all cases that the temperature and precipitation data were not normally distributed, an analysis of variance was realized with the nonparametric statistical of Kruskal and Wallis test, which is also known as *H* test and uses sample data ranges from three or more independent populations (Kruskal and Wallis, 1952). This test was used to identify significant differences between the temperature data and precipitation data from the three altitudinal strata. The statistic is described by the expression:

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Table 1. Agro-ecological intervals for the diagnosis of potential areas for six species of tropical grasses.

Species	Mean-annual temperature(°C)			Mean-annual precipitation (mm)			Soil texture		
	Op	Sp	Mg	Op	Sp	Mg	Op	Sp	Mg
Andropogon gayanus	22-28	28-32 15-22	0-15 >32	750-1400	400-750 1400-3000	0-400 >3000	Cr	Md	Fn
Brachiaria mutica	21-30	30-46 15-21	0-15 >46	1200-2000	500-1200 2000-4100	0-500 >4100	Cr	Md	Fn
Cenchrus ciliaris	18-27	5-18 27-42	0-5 >42	400-1000	100-400 1000-3500	0-100 >3500	Md	Fn	Cr
Chloris gayana	18-37	5-18 37-50	0-5 >50	500-1500	400-500 1500-2000	0-400 >2000	Md	Fn	Cr
Cynodon dactylon	18-35	6-18 35-40	0-6 >40	625-1750	400-625 1750-4300	0-400 >4300	Md	Cr-Fn	
Hyparrhenia rufa	23-28	11-23 28-32	0-11 >32	600-1400	500-600 1400-1600	0-500 >1600	Md	Cr	

Op,optimal; **Sp**,Suboptimal and supraoptimal; **Mg**=marginal; **Cr**=Coarse; **Md**=Medium, **Fn**=Fine.

Table 2. Results of Kolmogorov-Smirnov's normality test for temperature and precipitation data from three altitudinal strata.

Variable	gl	Kolmogorov-Smirnov statistic	Significance probability
Lowlands precipitation	53824	0.119	0.0001
Midlands precipitation	35501	0.158	0.0001
Highlands precipitation	9258	0.066	0.0001
Lowlands temperature	53824	0.061	0.0001
Midlands temperature	35501	0.046	0.0001
Highlands temperature	9258	0.018	0.0001

$$H = \frac{12}{N(N+1)} \Sigma_{i=1}^{j} \frac{Ri^2}{ni} - 3(N+1)$$

Where: J = the number of samples, n_i = the number of observations in the ^{i}th sample, N = Σ_{ni}, the number of observations in all samples combined, R_i = the sum of the ranks in the ^{i}th sample.

In order to perform the statistical analysis, temperature and precipitation were derived from each cell of the raster images of these variables for the three altitudinal strata studied. This information was extracted transforming the raster images to vector of points, which were exported using Idrisi Selva system to ascii files and these were opened and manipulated in Microsoft Excel system.

Diagnostic potential areas

Potential areas were determined using a multi-criterion analysis in Idrisi Selva system and considering a qualitative scheme of three categories: areas with optimal agroecological conditions (Op), areas with suboptimal agroecological conditions (Sp) and areas with marginal agroecological conditions (Mg). They were assumed to have optimal agroecological conditions, the areas in which all environmental factors of analysis were at an optimum level for forage species; suboptimal were classified as those areas in which at least one variable of diagnosis was found in non-optimal conditions (sub- optimal or supra- optimal) for growing; finally marginal areas were taken as the ones in which at least one of the diagnostic variables maintained development restricting values for forage species studied. The information to establish this categorization was obtained from literature review reported by Duran (2011). Table 1 describes the intervals of three variables used to diagnose potential areas. The slope of the ground for all species was graded by assigning an optimal condition for slopes from 0 to 8%, suboptimal condition for slopes from 8 to 20% and marginal condition for slopes greater than 20%. Soil depth was considered in two categories, according to information available in raster image used: deep soil (optimum condition) and shallow soils (suboptimal conditions). The analysis of potential areas was made considering as surface diagnosis only agricultural use areas.

RESULTS AND DISCUSSION

Statistical analysis

As shown in Table 2, and according to the results of theKolmogorov-Smirnov test (P <0.0001), temperature and precipitation data do not have a normal distribution in any of the altitudinal strata studied. Table 3 describes the basic statistics of temperature and precipitation by altitudinal stratum. According to the results of the Kruskal and Wallis test, both the temperature and precipitation varied significantly (P<0.001) among the three altitude

Table 3. Basic statistics of temperature and precipitation on three altitudinal strata.

Variable	n	Average	Standard deviation
Lowlands precipitation	53825	868	692.9
Midlands precipitation	35502	609	382.4
Highlands precipitation	9259	774.5	284.3
Lowlands temperature	53825	22.8	2.74
Midlands temperature	35502	17.7	2.22
Highlands temperature	9259	14.3	2.09

Table 4. Annual average values of mean temperature and accumulated precipitation for two climate scenarios in three altitudinal strata of the agricultural surface in Mexico.

Climatic scenarios	Models	Variables	Altitudinal strata		
			Lowlands	Midlands	Highlands
1961-1990		Temperature (°C)	22.8	17.7	14.3
		Precipitation (mm)	868.0	609.0	774.0
2040-2069	MPIM-ECHAM5	Temperature	25.4	21.0	17.0
		Precipitation	874.0	622.0	756.0
	MIROC3.2 (medres)	Temperature	25.7	20.5	17.4
		Precipitation	754.0	552.0	681.0
	UKMO_HadCM3	Temperature	25.5	20.4	16.7
		Precipitation	819.0	633.0	815.0

strata, so that the three topographical regions can be considered climatically different.

Climate changes in the agricultural areas of Mexico

The thermal variation ranging from 14.3°C at high altitudes to 22.8°C in low areas, combined with the variation of precipitation, produces great environmental diversity in agricultural areas of Mexico. The projections of temperature from the three GCM used, indicate a thermal increase in the range of 2.6 to 2.9, 2.7 to 3.3 and 2.4 to 3.1°C in low, mid and high lands, respectively (Table 4), passing through 1961 to 1990 period to 2040 to 2069 period, which translates into a decadal heating rate of 0.32 to 0.37, 0.34 to 0.42 and 0.30 to 0.39°C. This increase coincides with that recorded by Sivakumar et al. (2005), who estimated for Africa a warming of 0.2 to 0.5°C per decade in this century.

The thermal variation projected for the region of studyis important, as some areas will vary its temperature regime; such as areas of intermediate height that will go from a tempered condition (12-18°C of mean annual temperature, García, 1988), to a semiwarm condition (18-22°C, García, 1988, Medina et al., 1998), which will have positive effects on the surface with optimal conditions for growing tropical and subtropical species (Ruiz et al., 2011). However, the temperature increment is considered harmful for crops, since it may be shortening the crop production cycle of the actual varieties, and therefore reducing the final yield; especially if no adaptation measures are considered (Gornall et al., 2010; Ruiz et al., 2011). In the lowlands, which keep a warm temperature, near the maximum physiological thresholds of crops, the temperature increment projected in the present study may be detrimental due to the increase of heat stress and loss of water by evaporation (Gornall et al. 2010).

Regarding precipitation, the projections of the three GCMs do not maintain a coincidence as high as in the case of temperature, because while MIROC3.2 (medres) and UKMO_HADCM3 models indicate a decrease in precipitation of 13 and 6% in lowlands, MPIM-ECHAM5 model projects a slight increase of 0.7% in annual rainfall (Table 4). In addition, for midlands an increment of 2 and 4% in annual precipitation is projected, with MPIM-ECHAM5 and UKMO_HADCM3 models, respectively, and a 9.5% decrease with the MIROC3.2 (medres). In the highlands a decrease of 2 and 12% of precipitation is projected with MPIM-ECHAM5 and MIROC3.2 (medres) models, while an increase of 5% is visualized with UKMO_HADCM3 model. This lack of consistency in the modeling of future precipitation by different GCMs has been previously reported (IPCC, 2007) and it is

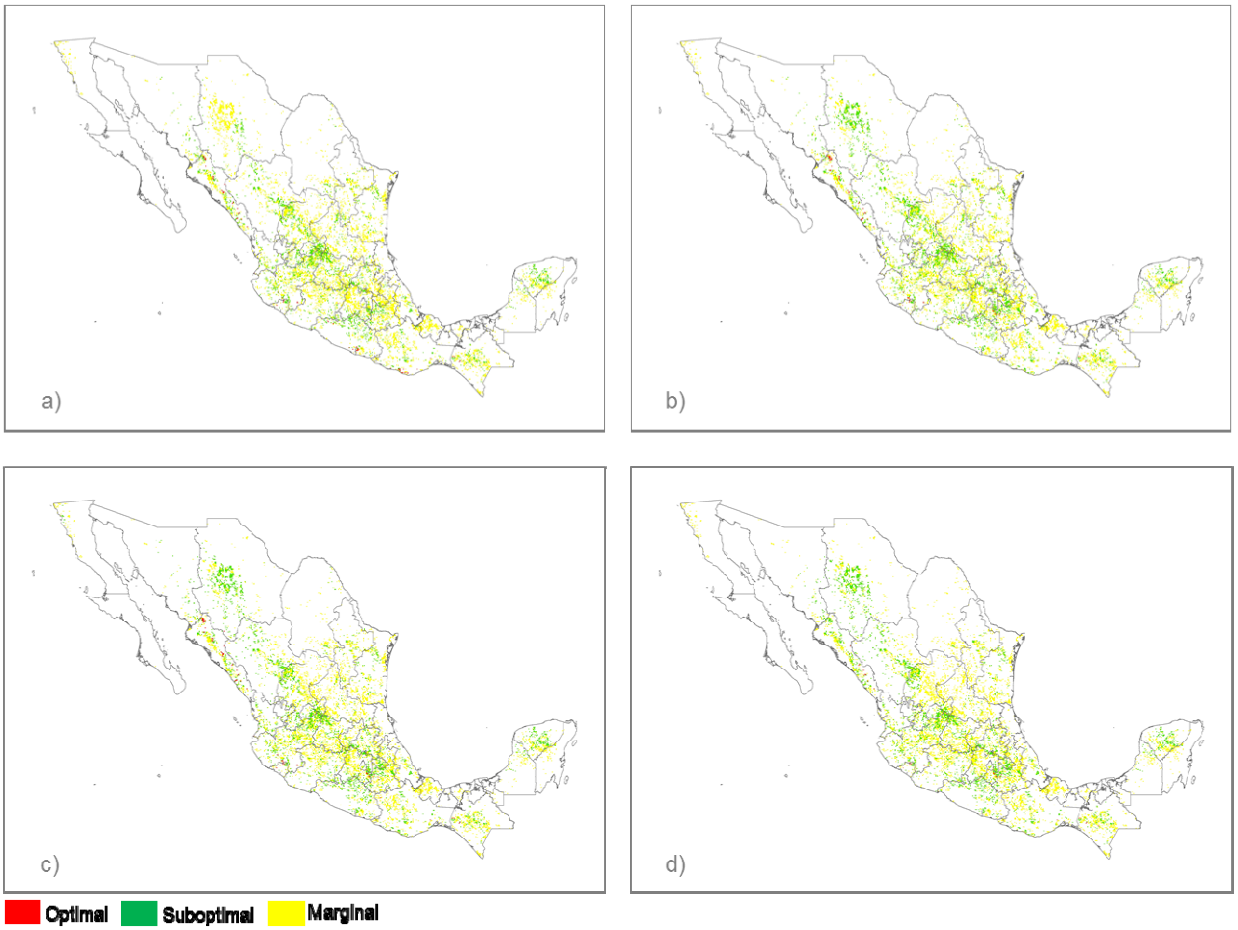


Figure 1. Potential areas for *A. gayanus*, under climatologies: a) 1961-1990, and 2040-2069, with three GCM: b) UKMO-HadCM3, c) MPIM-ECHAM5, d) MIROC3.2 (medres) and SRES A2.

emphasized in desert and semi-desert areas (Johnson and Sharma, 2009), condition that prevails in the Mexican territory. This is an important aspect, considering that rainfall is a relevant variable for hydroclimatological assessments such as crops productivity (Kumar et al., 2004; Sivakumar et al., 2005). Even little changes in rainfall may impact productivity (Lobell and Burke, 2008).

Potential areas for grasses

As expected for tropical grasses, optimal conditions for their cultivation were found mostly in lowlands during the reference period 1961 to 1990 (Figures 1 to 6), showing that climatic conditions of 0-1200 masl areas match better to the agroclimatic requirements from these grasses (FAO, 2000; Durán, 2011). For *C. ciliaris* and *C. gayana,* favorable environmental conditions were detected in the three altitudinal strata, as a result of their more ample environmental ranges (FAO, 2000).

In the maps of these figures, the effect of climate change over the grasses potential areas may also be seen. The sense of predictions of potential areas from GCMs coincided in four specie; they agree in predicting that optimal surface will decrease in lowlands and will increase in midlands and eventually in highlands for *C. ciliaris, A. gayanus* and *B. mutica*.

They also converge in establishing that *H. rufa* will increase its optimal surface in all altitudinal strata, showing that this species tolerates hotter environments and nowadays agricultural lands of México does not offer environments as hot as this species requires (Durán, 2011).

Decreasing potential areas in lowlands for grasses is in correspondence to the statement from Wan et al. (2005) and Bertrand et al. (2008a) who referred to possible negative effects on the prairies because of the high temperatures, especially in hot-dry regions, where plant physiological processes are directly affected by rising temperature.

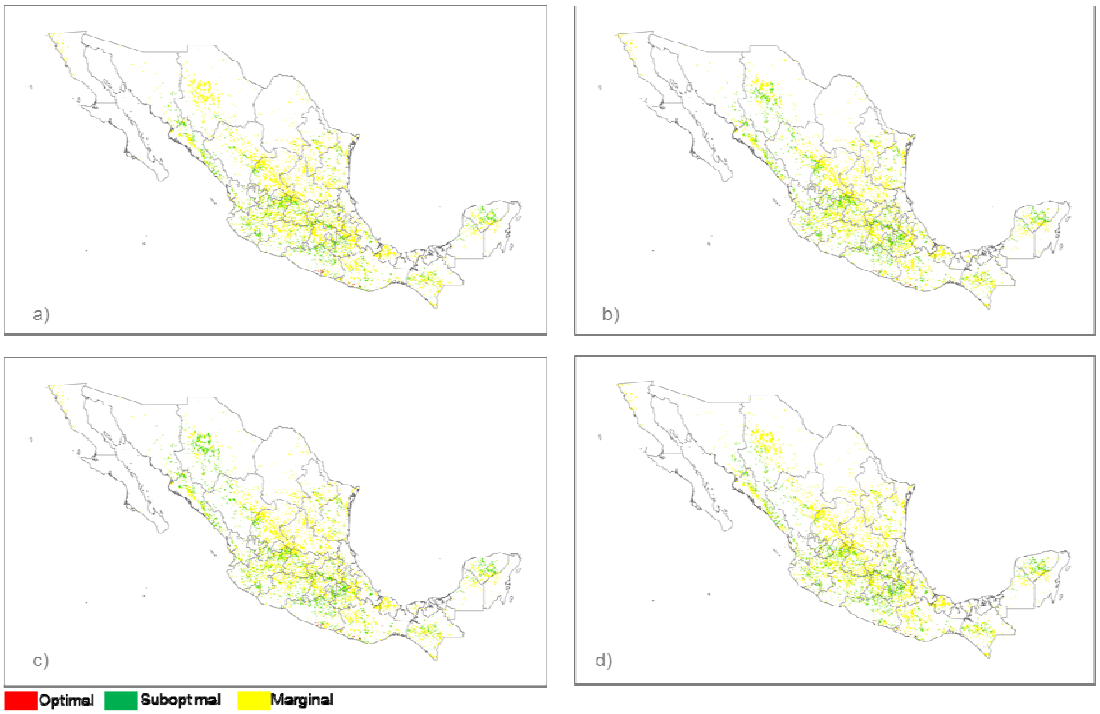


Figure 2. Potential areas for *B. mutica*, under climatologies: a) 1961-1990, and 2040-2069, with three GCM: b) UKMO-HadCM3, c) MPIM-ECHAM5, d) MIROC3.2 (medres) and SRES A2.

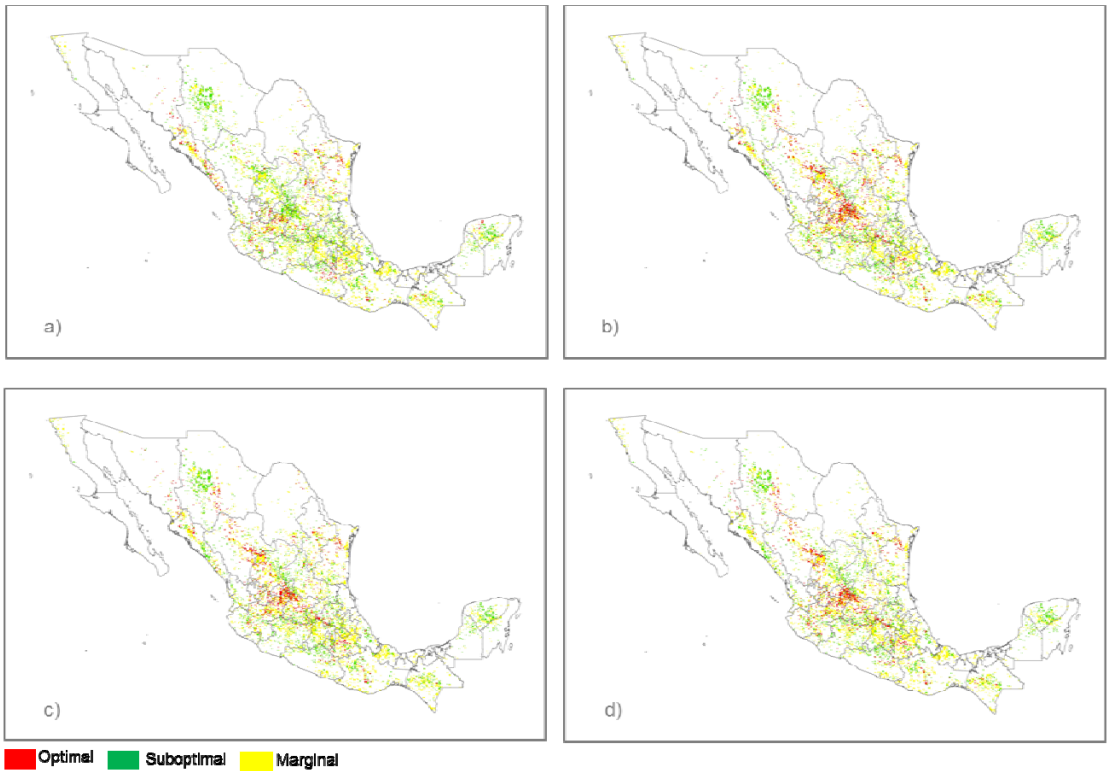


Figure 3. Potential areas for *C. ciliaris*, under climatologies: a) 1961-1990; and 2040-2069 with three GCM, b) (UKMO-HadCM3); c) MPIM-ECHAM5; d) MIROC3.2 (medres) and SRES A2.

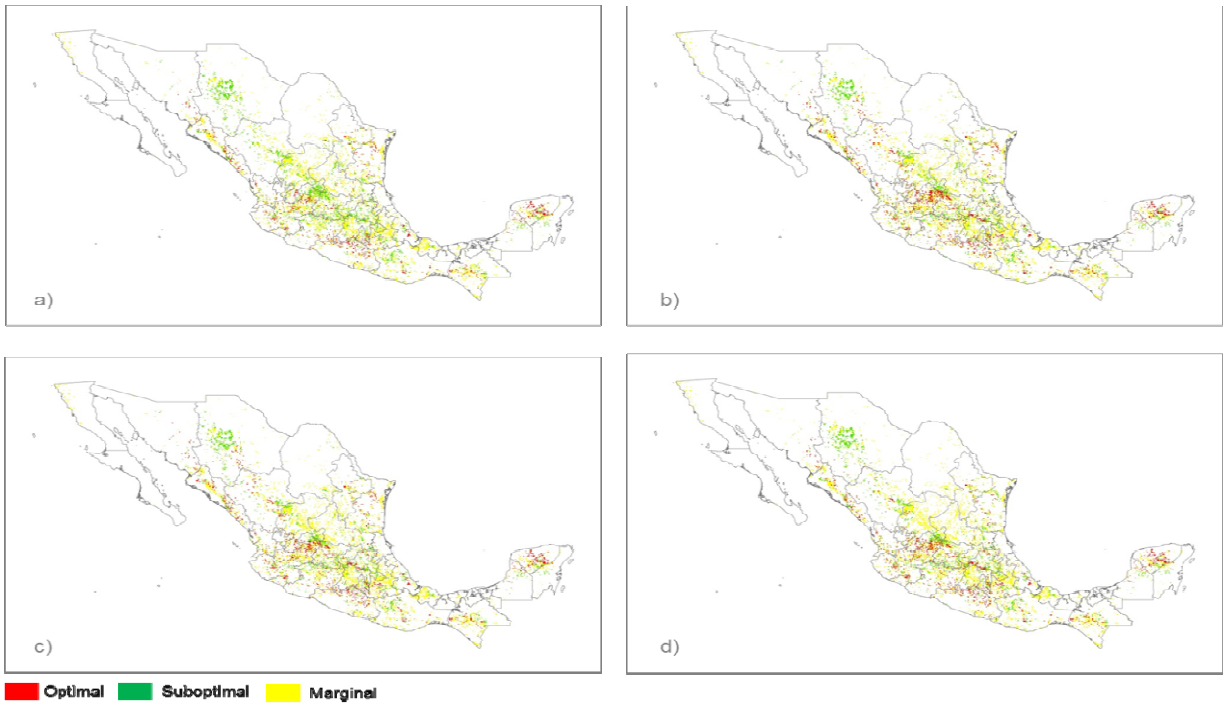


Figure 4. Potential areas for *C. gayana*, under climatologies: a) 1961-1990, and 2040-2069 with three GCM, b) UKMO-HadCM3, c) MPIM-ECHAM5, d) MIROC3.2 (medres) and SRES A2.

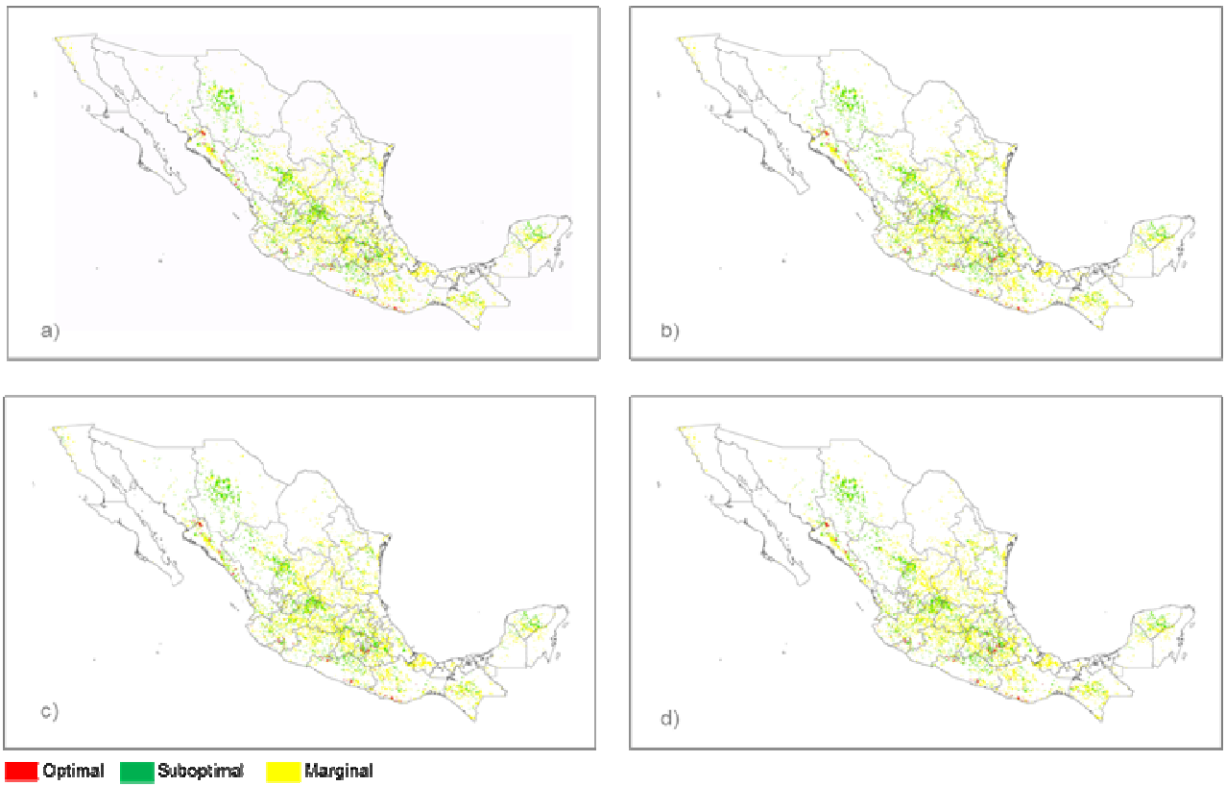


Figure 5. Potential areas for C. dactylon, under climatologies: a) 1961-1990, and 2040-2060 with three GCM, b) UKMO-HadCM3, c) MPIM-ECHAM5, d) MIROC3.2 (medres) and SRES A2.

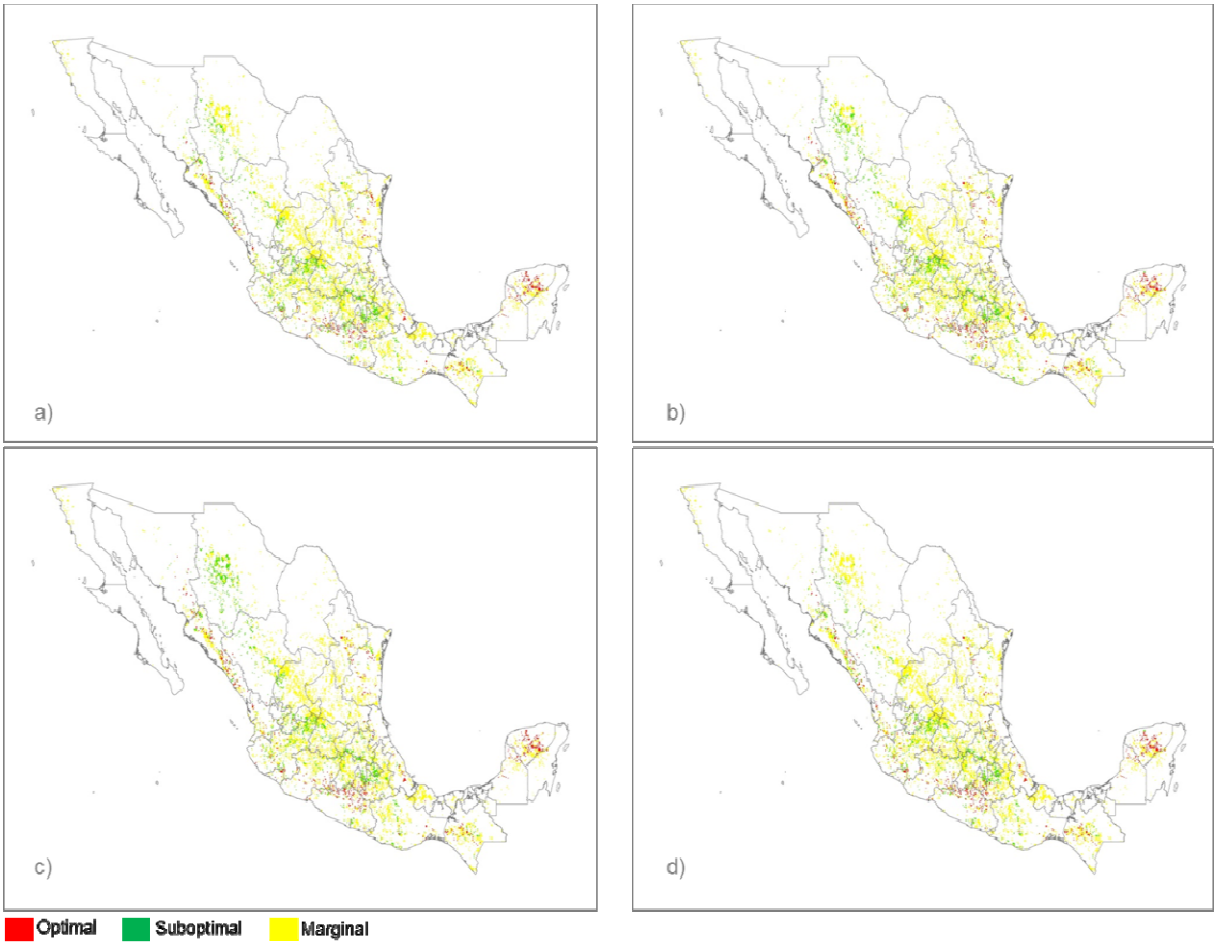


Figure 6. Potential areas for *H. rufa*, under climatologies: a) 1961-1990, and 2040-2069, with three GCM: b) UKMO-HadCM3, c) MPIM-ECHAM5, d) MIROC3.2 (medres) and SRES A2.

For *C. gayana* and *C. dactylon* climate predictions from MPI_ECHAM5 and UKMO_HADCM3 models yielded potential areas quite similar, with optimal surface in lowlands and midlands, superior to that from the reference climatology map (Figures 4 and 5). However, potential areas elaborated with the MIROC3.2 (medres) climatology (2040-2069) resulted sensitively different for lowlands, with an optimal surface 7% less than that from the reference climatology map. These opposite results are mainly due to the differences in the precipitation simulations from the GCMs, since MIROC3.2 (medres) estimated lower annual rainfall volumes in the three altitudinal strata (Table 4). This fact is evidencing that crops potential areas depiction is sensitive to the GCMs climate simulation variations even among GCMs that are considered similar in predicting climate change for México (Conde et al., 2006).

Differences among GCMs also were observed at determining suboptimal surfaces for grasses. However, based on three cases of complete coincidence (3 GCMs) and four coincidences between UKMO_HADCM3 and MIROC3.2 (medres) models, and four coincidences between UKMO_HADCM3 and MPI_ECHAM5 models, it may be stated that there is a tendency for suboptimal surface to increase in lowlands and to decrease in midlands and highlands, which is related to the tendencies observed for optimal surfaces in the three altitudinal strata (Table 5).

Some interesting cases derived from dynamic potential areas, promoted by climate change, involve the appearance of optimal areas in midlands and highlands of the northern and center regions of the country. This is the case for *C. ciliaris, C. gayana* and *H. rufa* (Figures 3, 4 and 6). These regions had already been reported with changes in crops patterns due to climate change (Ramírez et al., 2011; Santillán et al., 2011).

According to the results, it may be concluded that climate change will cause that tropical grasses potential areas move towards midlands and highlands in the future. Thus, a redistribution of crops lands probably will

Table 5. Potential areas for six grasses in three altitudinal strata and two climatic scenarios in México.

Grass	Altitude zone	Scenario (1961-1990)		Scenario 2040-2069					
				MPIM-ECHAM5		MIROC3.2 (medres)		UKMO_HadCM3	
		Optimal and suboptimal potential areas (ha)							
		Optimal	Suboptimal	Optimal	Suboptimal	Optimal	Suboptimal	Optimal	Suboptimal
Andropogon gayanus	Lowlands	164,122	1,894,659	147,280	1,935,292	59,965	1,964,792	161,064	1,909,548
	Midlands	4,061	2,643,665	22,311	2,970,164	22,295	2,800,376	22,311	3,207,595
	Highlands	0	597,224	0	1,153,472	0	1,142,503	0	1,182,214
Brachiaria mutica	Lowlands	69,631	1,943,637	57,334	1,974,806	49,105	1,861,253	59,004	1,961,888
	Midlands	0	1,726,758	0	2,296,665	0	1,619,046	2,010	2,218,312
	Highlands	0	409,153	0	907,769	0	816,231	0	996,192
Cenchrus ciliaris	Lowlands	786,747	1,915,465	463,710	2,238,502	403,483	2,298,729	510,597	2,191,615
	Midlands	759,409	3,558,706	1,755,678	2,562,438	1,721,815	2,596,300	1,949,280	2,368,835
	Highlands	6,005	1,248,036	378,823	875,218	410,878	843,163	414,789	839,252
Chloris gayana	Lowlands	1,500,584	1,062,650	1,515,397	1,078,930	1,425,710	1,118,464	1,504,117	1,082,884
	Midlands	756,726	3,023,112	1,459,904	2,154,841	1,237,426	2,214,712	1,534,320	2,325,593
	Highlands	12,149	1,202,442	238,395	932,544	264,651	861,163	294,308	922,195
Cynodon dactylon	Lowlands	301,827	1,765,121	307,464	1,783,276	280,727	1,746,071	311,476	1,761,177
	Midlands	48,632	3,133,221	92,691	2,924,213	84,795	2,741,770	88,809	3,176,774
	Highlands	0	1,313,922	16,225	1,252,024	38,490	1,172,591	22,297	1,295,578
Hyparrhenia rufa	Lowlands	1,165,892	756,257	1,346,185	584,590	1,229,833	597,349	1,360,760	544,855
	Midlands	48,672	1,860,988	239,178	2,059,540	267,279	1,339,382	239,097	1,992,730
	Highlands	0	1,034,744	0	1,018,467	0	878,712	0	1,124,049

take place in these altitudinal zones, during the present century.Since in the present, the midlands include most of the agricultural surface, this redistribution may not to have a high impact; however when atmospheric warming and climate change push the crops to migrate to highlands, it will impose a complicated situation since nowadays only 18% of agricultural surface is located within highlands.

CONCLUSIONS

The temperature projections of the three GCM used, consistently indicate temperature increase in the range of 2.6 to 2.9, 2.7 to 3.3 and 2.4 to 3.1°C in low, mid and high lands, respectively, going from the 1961 to 1990 period to the 2040 to 2069 period. Precipitation projections were not that consistent among the models, since some indicate decreased rainfall and others an increment, but in all cases these changes are located in the range from 0.7 to 13%. Two of the three models reported a decrement in annual precipitation for the period 2040 to 2069 in lowlands, an increment of 2 to 4% in midlands, and a drop precipitation of 2 to 12% in highlands. The MIROC3.2 (medres) model simulated consistently lower annual precipitation amounts in the three altitudinal strata.

The projected climate changes will affect the amount and altitudinal distribution of the surface with optimal and suboptimal agroclimatic conditions for the growth of the six grass species studied. The potential cultivation surface with optimal agroclimatic conditions currently focuses more on lowlands (0 to 1200 m) for all grasses, while the potential surface with suboptimal conditions basically is grouped in intermediate altitude lands (1200 to 2200 m). With expected climatic changes, most of the optimal surface will remain in lowlands, but will tend to decrease in these areas for *C. ciliaris, A. gayanus, and B. mutica* at a rate of 35 to 49 %, 2 to 63% and 15 to 30%, respectively. These impacts will be reflected most on the optimal surface for *C. ciliaris,* which will tend to migrate mainly to midlands. The surface with optimal conditions for *C. gayana* in lowlands will tend to stay, but in midlands it will increase between 63 and 103%. A similar case is that of *C. dactylon* which its optimum surface condition will tend to stay in the same amounts in lowlands, but will increase between 74 and 90% in midlands. Finally for *H. rufa*, the surface with optimum conditions will increase from 5 to 17% in lowlands and from 391 to 449% in midlands.

In highlands, potential areas for grasses were detected basically as suboptimal. However, with climate change *C.ciliaris, C. gayana* and *C. dactylon* will increase their optimal surface dramatically. A different situation was detected for *A. gayanus, B. mutica* and *H. rufa* which resulted with non-optimal surface neither in the reference climatology nor in the climate change climatologies.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This article was supported by the INIFAP project “Cambio Climático y su Impacto sobre el Potencial Productivo Agrícola, Forrajero y Forestal en México”.

REFERENCES

Attipalli RR, Girish KR, Agepati SR (2010). The impact of global elevated CO2 concentration on photosynthesis and plant productivity. Curr. Sci. 99(1):46-57.

Bertrand A, Prevost D, Bigras FJ, Lalande R, Tremblay GF, Castonguay Y, Belanger G (2008a). Alfalfa response to elevated CO_2 varies with the symbiotic rhizobial strain. Plant Soil 301:173–187. http://dx.doi.org/10.1007/s11104-007-9436-9

Conde C, Ferrer R, Orozco S (2006). Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study. Atmósfera 19(3):181-194.

Deryng D, Sacks W, Barford C, Ramankutty N (2011). Simulating the effects of climate and agricultural management practices on global crop yield. Glob. Biogeochem. Cycles GB2006 25:18.

Díaz PG, Guajardo PRA, Medina GG, Sánchez CI, Soria RJ, Vázquez AMP, Quijano CJA, Legorreta PF, Ariel RCJ (2012). Potencial productivo de especies agrícolas de importancia socioeconómica en México. 1a. Ed. INIFAP. Xalapa, Ver., México P. 140.

Durán PN (2011). Cambio climático y potencial productivo de especies forrajeras en la región Centro-Occidente de México. Tesis doctoral. Universidad de Guadalajara-CUCBA. Zapopan, Jalisco, México P. 180.

Eastman JR (2012). Idrisi Selva Manual, Manual Version 17. Clark Labs, Clark University. Worcester, Mass., USA. P. 322.

FAO. Ecocrop (2000). Version Online. URL: http://www.ecocrop.fao.org.

Friend AD, Geider RJ, Behrenfeld MJ, Still CJ (2009). Photosynthesis in global-scale models. In Photosynthesis in silico (eds Laiska, A., Nedbal, L. and Govindjee), Springer, The Netherlands pp. 465–497. http://dx.doi.org/10.1007/978-1-4020-9237-4_20

García E (1988). Modificaciones al sistema de clasificación climática de Köppen (para adaptarlo a las condiciones de la República Mexicana). 4a. Ed. Offset Larios. México, D.F. P. 219.

Ghannoum O, von Caemmerer S, Ziska LH, Conroy JP (2000). The growth response of C4 plants to rising atmospheric CO_2 partial pressure: A reassessment. Plant Cell Environ. 23:931–942. http://dx.doi.org/10.1046/j.1365-3040.2000.00609.x

Gornall J, Betts R, Burke E, Clark R, Camp J, Willet K, Wiltshire A (2010). Implications of climate change for agricultural productivity in the early twenty-first century. Phil. Trans. R. Soc. B. 365:2973-2989. http://dx.doi.org/10.1098/rstb.2010.0158

Hatfield JL, Boote KJ, Fay P, Hahn P, Izaurralde L, Kimball RC, Mader BA, Morgan T, Ort J, Polley D, Thomson WA, Wolfe D (2008). Agriculture. In The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. U.S. Climate Change Science Program and the Subcommittee on Global Change Res., Washington, DC.

Hatfield JL, Boote KJ, Kimball BA, Ziska LH, Izaurralde RC, Ort D, Thomson AM, Wolfe D (2011). Climate impacts on agricultura: Implications for crop production. Agron. J. 103:351-370. http://dx.doi.org/10.2134/agronj2010.0303

Hegerl GC, Zwiers FW, Braconnot P, Gillet NP, Luo Y, Marengo JA, Nicholls N, Penner JE, Stott PA (2007). Understanding and Attributing Climate Change. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate 83 Change., S. e. al., Ed., Cambridge University Press.

Hsiang SM, Kile CM, Cane AM (2011). Civil conflicts are associated with the global Climate. Nature. 476:438–441. http://dx.doi.org/10.1038/nature10311

IBM Corp. (2010). IBM SPSS Statistics for Windows, version 19.0. Armonk, NY: IBM Corp.

Instituto Nacional de Estadística Geografía e Informática (INEGI). 2009. Guía para interpretación cartográfica: Uso de suelo-vegetación

Serie III. D. F., México. P. 71.
Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007: mitigation of climate change. Contribution of working group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Metz B, Davidson O, Bosch P, Dave R, Meyer L (eds.). Cambridge University Press, UK. and USA, P. 851.
Izaurralde RC, Thomson AM, Morgan JA, Fay PA, Polley HW, Hatfield JL (2011). Climate impacts on agriculture: implications for forage and rangeland production. Agron. J. 103:371-381. http://dx.doi.org/10.2134/agronj2010.0304
Johnson F, Sharma A (2009). Measurement of GCM skill in predicting variables relevant for hydroclimatological assessments. J. Climate, 22:4373–4382. http://dx.doi.org/10.1175/2009JCLI2681.1
Justin EB, Desai RA, Dirmeyer PA, Foley AJ (2012). Effects of land cover change on moisture availability and potential crop yield in the world's breadbaskets. Environ. Res. Lett. 7:1-9.
Kimball BA, Kobayashi K, Bindi M (2002). Responses of agricultural crops to free-air CO_2 enrichment. Adv. Agron. 77:293-368. http://dx.doi.org/10.1016/S0065-2113(02)77017-X
Kimball BA (2007). Global change and water resources. In: Lascano
RJ, Sojka RE (ed.). Irrigation of agricultural crops. 2nd edition. ASA, CSSA and SSSA. Madison, WI. Agron. Monogr. 30:627-654. http://dx.doi.org/10.1111/j.13652486.2007.01430.xhttp://dx.doi.org/10.1111/j.1365-2486.2007.01486.x
Kruskal WH, Wallis AW (1952). Use of ranks in one-criterion variance analysis. Journal of the American Statistical Association 47(260):583-621. http://dx.doi.org/10.1080/01621459.1952.10483441
Kumar KK, Kumar KR, Ashrit RG, Deshpande NR, Hansen JW (2004). Climate impacts on Indian agriculture. Int. J. Climatol. 24:1375-1393.http://dx.doi.org/10.1002/joc.1081
Leakey ADB, Ainsworth EA, Bernacchi CJ, Rogers A, Long SP, Ort DR (2009). Elevated CO_2 effects on plant carbon, nitrogen and water relations: six important lessons from FACE. J. Exp. Bot. 60:2859–2876.http://dx.doi.org/10.1093/jxb/erp096 PMid:19401412
Lobell DB, Burke MB (2008). Why are agricultural impacts of climate change uncertain? The importance of temperature relative to precipitation. Environ. Res. Lett. 3:1-8. http://dx.doi.org/10.1088/1748-9326/3/3/034007
Medina GG, Ruiz CJA, Martínez PAR (1998). Los climas de México: una estratificación ambiental basada en el componente climático. Libro téc 1. SAGAR-INIFAP, P. 104.
Ojeda BW, Sifuentes IE, Í-iguez CM, Montero MMJ (2011). Impacto del cambio climático en el desarrollo y requerimientos hídricos de los cultivos. Agrociencia. 45:1-11.
Ramírez LMR, Ruiz CJA, Medina GG, Jacobo CJL, Parra QRA, Ávila MMR y Jesús Pilar Amado ÁJP (2011). Perspectivas del sistema de producción de manzano en Chihuahua, ante el cambio climático. Rev. Mex. de Cs Agríc. Pub. Esp. (2):265-279.
Ruiz CJA, Medina GG, Ramírez DJL, Flores LHE, Ramírez OG, Manríquez OJD, Zarazúa VP, González EDR, Díaz PG, De la Mora OC (2011). Cambio climático y sus implicaciones en cinco zonas productoras de maíz en México. Rev. Mex. de Cs Agríc. Pub. Esp. (2):309-323.
Santillán ELE, Blanco MF, Magallanes QR, García HJL, Cerano PJ, Delgadillo RO, Valdez CRD (2011). Tendencias de temperatura extremas en Zacatecas, México. Rev. Mex. De Cs Agríc. Pub. Esp. (2):207:219.
Sivakumar MVK, Das HP, Brunini O (2005). Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi-arid tropics. In: increasing climate variability and change. Salinger JM, Sivakumar VK, Motha RP (eds.). Springer, USA, pp. 31-72.
Trenberth KE, Jones PD, Ambenje P, Bojariu R, Easterling DR, Kleint-Tank A, Parker D, Rahimzadeh F, Renwick JA, Rusticucci M, Soden B, Zhai P (2007). Observations: Surface and Atmospheric Climate Change. Climate Change 2007: The Physical Science Basis. Contribution of WG I to the Fourth Assessment Report of the IPCC., S. e. al., Ed., Cambridge University Press.
Tubiello FN, Soussana JF, Howden SM (2007). Crop and pasture response to climate change. Proc. Natl. Acad. Sci. USA. 104:19686-19690. http://dx.doi.org/10.1073/pnas.0701728104, PMid:18077401 PMCid:PMC2148358
Verena S, Navin R, Jonathan AF (2012). Comparing the yields of organic and conventional agriculture. Nature. 00(000): pp. 1-6.
Wan S, Hui D, Wallace L, Luo Y (2005). Direct and indirect effects of experimental warming on ecosystem carbon processes in a tallgrass prairie. Global Biogeochem. Cycles 19:2014 10.1029/2004GB002315. http://dx.doi.org/10.1029/2004GB002315
Wang G (2005). Agricultural drought in a future climate: results from 15 global change models participating in the IPCC 4th assessment. Clim. Dyn. 25:739–753. http://dx.doi.org/10.1007/s00382-005-0057-9
Woodhouse CA, Meko DM, MacDonald GM, Stahle DW, Cook ERA (2010). 1,200-year perspective of 21st century drought in southwestern NorthAmerica. Proc.Natl Acad. Sci. USA 107:21283–21288. http://dx.doi.org/10.1073/pnas.0911197107