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Management options to increase groundnut productivity under climate change at selected sites in India

PIARA SINGH*, N. P. SINGH, K. J. BOOTE[1], S. NEDUMARAN, K. SRINIVAS and M. C. BANTILAN

ICRISAT, Patancheru, 502 324, Andhra Pradesh, India
[1]Agronomy Dept., University of Florida, IFAS, Gainesville, FL32611-0290, USA
**Corresponding author: p.singh@cgiar.org*

ABSTRACT

Climate change is projected to alter the growing conditions of groundnut crop differently in different regions of India. The CROPGRO-Groundnut model was used to quantify the impact of climate change on the productivity of groundnut at three sites (Anantapur, Mahboobnagar and Junagadh) in India.Increase in temperature significantly ($p<0.05$) decreased pod yield of groundnut at all the sites by 2050. But the net effect of changes in temperature, rainfall and CO_2 was 4% decrease in yieldat Anantapur and 11% increase at both Mahboobnagar and Junagadh. A number of agronomic practices evaluated under climate change atAnantapur showed that the maximum increase in yield was simulated with supplemental irrigation, followed by delay in sowing and growing a longer maturity variety. At Mahboobnagar, the maximum yield gain was with delayed sowing, followed by growing a longer maturity variety, supplemental irrigation and application of crop residues. At Junagadh, the yield increase was the maximum with supplemental irrigation, followed by application of crop residues. It is concluded that the relative contribution and prioritization of agronomic practices to increase groundnut yield under climatechange varied with the region and the CROPGRO-Groundnut modelwas useful in quantifying such benefits.

Key words: Agronomic optimization,Climatic factors,Peanut, Crop modeling, CROPGRO-Peanut model

Increasing concentration of greenhouse gases in the atmosphere is warming the globe, which is causing climate change in terms of higher air temperatures, changing precipitation patterns and increased frequency of extreme weather events such as floods, heavy storms and droughts (IPCC, 2007). Depending upon the location on the globe, the plant growth and yield of crops will be negatively or positively affected by the climate change (Howden *et al*., 2007). Increasing temperatures affect growth and development of crops, thus influencing potential yields. A critical variable is the number of days a crop is exposed to temperatures above specific thresholds at critical growth stages, i.e. flowering, pollination or grain-filling, thus reducing the quantity and quality of economic yield (Prasad *et al*., 2003). Free air carbon enrichment (FACE) experiments indicated crop productivity to increase in the range of 15-25% for C3 crops, like wheat, rice and groundnut, with the increase in CO_2 concentration in the atmosphere (Tubiello *et al*., 2007). The positive effects of enhanced CO_2 will continue alongside the negative effects of supra-optimal temperatures until the temperature thresholds are reached. When climate changes are relatively small, many current agronomic techniques are available to help farmers adapt. These early-stage adaptations include varying sowing dates and cultivars, fertilization, irrigation scheduling, soil management such as reduced tillage and residue management, changing to better-adapted alternative crops and increasing crop diversity(Aggarwal, 2008 and Howden *et al*., 2007).Because agriculture will not experience the same magnitude of vulnerability to climate change in all regions, site-specific cropping systems and management practices will be needed to match yield potential with inputs, soil fertility and the range of climate variability in each area. Research technologies and management tools that can accelerate the adaptation of cropping systems include simulation modeling and remote sensing (Boote *et al*., 2011).

Groundnut (*Arachishypogaea* L.) is an important food and oilseed crop grown by small and marginal farmers in diverse agro-climatic environments in India. In view of the increasing population and anticipated climate change, production must continue to increase to meet the current and future demand for edible oil and vegetable protein in the country. This may be possible through improved agronomic management and genetic

Table 1: Baseline (Base) climate and projected increase in maximum and minimum monthly temperatures and percent change in monthly rainfall by 2030 and 2050 at the three sites as per the UKMO-HADCM3 GCM model for the SRES A1B scenario.

	Anantapur			Mahboobnagar			Junagadh		
	Base	Projected		Base	Projected		Base	Projected	
Month	1973-2002	2030	2050	1975-2004	2030	2050	1985-2007	2030	2050
				Maximum temperature (°C)					
Jun-Oct	32.0-35.4	1.1-1.5	1.9-2.6	30.4-34.9	0.8-1.7	1.4-2.8	30.7-35.7	0.1-1.1	0.2-1.8
				Minimum temperature (°C)					
Jun-Oct	22.0-24.4	1.2-1.9	2.0-3.2	21.6-24.7	1.0-2.0	1.7-3.4	24.0-27.1	1.1-1.7	1.8-2.9
				Rainfall (mm) and % change					
Jun	55	-7	-13	107	-11	-18	99	-31	-50
Jul	74	-11	-16	173	0	0	327	12	19
Aug	87	-3	-3	187	6	12	148	32	55
Sept	140	0	-1	163	5	9	67	36	54
Oct	99	-8	-13	94	4	6	43	25	45
Total	455			724			684		

improvement of the crop to suite the target environments considering both the current and future climates. Recently, Singh *et al.* (2012) evaluated various genetic traits of groundnut for enhancing its productivity and adaptation to climate change in groundnut growing regions ofIndia. However, there is no published work on agronomic aspects of adaptation of groundnut to projected climate change, especially in the semi-arid tropical environments. Using CROPGRO-Groundnut model, we quantified the impact of climate change on the productivity of groundnut and evaluated various agronomic options to increase its productivity under climate change at selected sites in India where groundnut is the dominant crop.

MATERIALS AND METHODS

Study sites

The simulation study of groundnut crop was carried out for three sites in India. The sites were Anantapur (14.68° N Lat., 77.62° E Long.) and Mahboobnagar (16.75° N Lat., 78.00° E Long.) in the state of Andhra Pradesh and Jungadh (21.31° N Lat., 70.36° E Long.) in the state of Gujarat. Among these, Anantapur and Jungadh represent the major groundnut growing areas of the country. The groundnut cultivars used in the study were JL 24 and M 335. JL 24 represents farmers' preference for the Spanish type of groundnut cultivars grown at the Anantapur and Maboobnagar sites; whereas M 335 represents the Virginia types grown by farmers at the Junagadh site. The baseline and climate change characteristics of the sites are given in Table 1.

The crop model

We used the CROPGRO-Groundnut model to quantify the impact of climate change on groundnut productivity and to evaluate various agronomic management practices for increasing its productivity at the target sites. The major components of the model are vegetative and reproductive development, carbon balance, water balance and nitrogen balance (Boote *et al.*, 1998). It simulates groundnut growth and development using a daily time step from sowing to maturity and ultimately predicts yield. The physiological processes that are simulated describe crop response to the major weather factors including temperature, precipitation and solar radiation and include the effect of soil characteristics on

Table 2: Impact of changes in temperature (T), rainfall (R) and CO_2 on days to maturity and pod yield of groundnut at the three sites for the 2030 and 2050 time slices

Time period	Climate change	Maturity (d)	Pod yield kg ha^{-1}	% Change
Anantapur				
1973-2002	Baseline	106	1230	
2030	T + R	107	1060	-13
2030	T + R + CO_2	107	1190	-3
2050	T + R	108	980	-20
2050	T + R + CO_2	108	1180	-4
LSD (p=0.05)	-	-	75	-
Maboobnagar				
1975-2004	Baseline	108	2250	
2030	T + R	108	2060	-8
2030	T + R + CO_2	108	2360	5
2050	T + R	109	2000	-11
2050	T + R + CO_2	109	2510	11
LSD (p=0.05)	-	-	94	-
Junagadh				
1985-2007	Baseline	124	2230	
2030	T + R	124	2180	-2
2030	T + R + CO_2	124	2430	9
2050	T + R	124	2060	-7
2050	T + R + CO_2	124	2480	11
LSD (p=0.05) [a]	-	-	135	-

[a] LSD (p=0.05): Least significant difference at 5% level of probability.

water availability for crop growth.Soil water balance is a function of rainfall, irrigation, transpiration, soil evaporation, runoff from the soil surface and drainage from the bottom of the soil profile. Daily surface runoff of water is calculated using the USDA Soil Conservation Service (SCS) curve number technique (Soil Conservation Service, 1972). The runoff curve number (CN) is supplied as input, which ranges from 0 (no runoff) to 100 (all runoff) based on soil type, land cover and surface residue applied. In the model, high temperature influences growth and development and reduces allocation of assimilates to the reproductive organs through decreased pod set and seed growth rate (Boote *et al.*, 2010). Increased CO_2 concentration in the atmosphere increases crop growth through increased leaf-level photosynthesis. Increased CO_2 concentration also reduces transpiration from the crop canopy via an empirical relationship between canopy conductance and CO_2concentration. Thus the model has the potential to simulate crop growth and development of groundnut cultivars under climate change conditions, such as high air temperatures, variability in rainfall and increased CO_2 concentrations in the atmosphere that ultimately result in final crop yields at maturity.The minimum data set required to simulate a crop includes site characteristics, daily weather data (solar radiation, maximum and minimum air temperatures and precipitation),physical and chemical propertiesof the soil profile and crop management data. The cultivar data include the genetic coefficients (quantified traits) which distinguish one cultivar from another in terms of crop development and growth.The details on minimum data set required for model execution and the calibration and

Table 3: Impact of three sowing conditions on pod yield (kg ha^{-1}) of groundnut at the three sites.

	Sowing conditions					
	NS/BC[a]	NS/CC[a]		DS/CC[a]		
Site	Yield	Yield	% change	Yield	% change	LSD (p=0.05)[b]
Anantapur	1230	1180	-4	1440	18	151
Mahbhoobnagar	2250	2500	11	2610	16	115
Junagadh	2230	2480	11	2380	7	153

[a] NS/BC: Normal sowing under baseline climate; NS/CC: Normal sowing under climate change; DS/CC: Delayed sowing under climate change; [b] LSD (p=0.05): Least significant difference at 5% level of probability.

validation of the two cultivars (JL 24 and M 335) to determine their genetic coefficients have been given inthe paper by Singh *et al.* (2012). The soil profile data for the target siteswere obtained from the soil survey bulletins published by the National Bureau of Soil Survey and Land Use Planning, Nagpur, India (Lal *et al.*,1994).The soil is an Alfisol at Ananatpur and an Inceptisol at both Mahbhoobnagarand Jungadh. The extractable water holding capacity of soils at Anantapur, Mahbhoobnagar and Junagadh is 95 mm, 125 mm and 200 mm, respectively. The baseline runoff curve numbers are 80, 73 and 76 for the respective three sites.Long-term records of weather data for the sites were obtained from the India Meteorological Department, Pune, India.

Projected climate change at the target sites

Statistically downscaled (delta method) projected climate change data as predicted by the UKMO-HADCM3 GCM model for the SRES A1B scenariofor the 2030 and 2050time slices and the WorldClim baseline climate data (1960-90) were downloaded for the target sites from the CIAT's climate change portal (http:/ccafs-climate.org// download_sres.html#down) (Table 1). Monthly changes in maximum and minimum temperature and rainfall, with reference to the baseline climate, along with CO_2 increase as per the ISAM model (IPCC, 2001) were input to the 'environmental modifications section' of the crop management files (.PNX) of the groundnut model. Starting with the first day of simulation, these climate change values modified the observed baseline weather data of a given month until it read the new set data for the next month.

Simulating the impact of climate changeand adaptation strategies

The CROPGRO-Groundnut model coupled with the seasonal analysis program available in DSSAT v4.5 (Hoogenboom *et al.*, 2010) was used to simulate the impact of climate change and adaptation strategies on groundnut productivity. Simulations were carried out for the baseline climate and the projected climate change by 2030 and 2050 for each site. For each time slice the impacts of changes in temperature and rainfall (T+R) and changes in temperature, rainfall and CO_2 (T+R+CO_2) were evaluated separately to quantify the impact of CO_2 concentration on crop yields. The CO_2 concentration level considered were 380 ppm for baseline climate, 430 ppm for 2030 and 530 ppm for 2050 (IPCC, 2001).For each site, the simulations were initiated on 15 May each year and the soil profile was considered to be at the lower limit of soil water availability on that day. Under normal sowing conditions the sowing window was 1 July to 15 August for Anantapur, 1 June to 15 July for Mahboobnagar and 15 June to 30 July for Junagadh considering the onset of rainy season at these target sites. The simulated crop was sown on the day when the soil moisture content in the top 30-cm soil depth had reached at least 40% of the extractable water-holding capacity during the sowing window. At the time of sowing, N and P at 20 kg ha^{-1} each were applied as diammonium phosphate. A plant population of 25 plants m^{-2} and rowspacing of 30 cm were considered for simulating groundnut growth. At all the sites the crop was grown rainfed in the model. Simulations were done for 30 years (1973-2002) for Anantapur, 30 years (1975-2004) for Mahboobnagar and 22 years (1985-2007) for Junagadh. The crop was considered free from pests and diseases.Simulation of adaptation options was carried out for theT+R+CO_2climate change scenario of the 2050 time slice only. These simulations were carried out for the three sowing conditions: normal sowing under baseline climate (NS/BC); normal sowing under climate

Table 4: Effect of individual and combinations of agronomic management practices on pod yields (kg ha^{-1}) groundnut for the sowing conditions under climate change at Anantapur, Mahbhoobnagar and Junagadh.

Management Practices	Anantapur DS/CC Yield	Anantapur % Change	Mahboobnagar DS/CC Yield	Mahboobnagar % Change	Junagadh NS/CC Yield	Junagadh % Change
Standard agronomy(SA)	1440	-	2610	-	2480	-
SA, 20 plants m^{-2}	1450	1	2560	-2	2470	0
SA, 30 plants m^{-2}	1440	-1	2670	2	2480	0
SA, N application (+N)	1470	2	2650	1	2480	0
SA, Crop residue (CR)	1510	4	2800	7	2580	4
SA, *In-situ* water conservation (WC)	1530	6	2670	2	2550	3
SA, Short duration variety (SHORTVAR)	1290	-11	2250	-14	2480	0
SA, Long duration variety (LONGVAR)	1570	9	2850	9	2420	-2
SA, Supplemental irrigation (SI)	1920	33	2820	8	2630	6
SA, 20 plants m^{-2}, +N	1490	3	2700	3	2480	0
SA, 20 plants m^{-2}, +N, CR	1550	7	2880	10	2590	5
SA, 20 plants m^{-2}, +N, CR, WC	1600	11	2890	11	2600	5
SA, 30 plants m^{-2}, +N, CR, WC, SHORTVAR	-	-	-	-	2610	5
SA, 30 plants m^{-2}, +N, CR, WC, SHORTVAR, SI	-	-	-	-	2740	11
SA, 20 plants m^{-2}, +N, CR, WC, LONGVAR	1750	21	3140	20	-	-
SA, 20 plants m^{-2}, +N, CR, WC, LONGVAR, SI	2200	52	3310	27	-	-
LSD (p=0.05)	99	-	89	-	92	-

% Change: Percent change in pod yield with reference to the pod yield obtained with standard agronomy; For the explanation of other abbreviations, see Table 3

change (NS/CC) and delayed sowing under climate change (DS/CC). The normal sowing windows for the sites have been described in the preceding section. Delayed sowing windows were 15 July to 15 August for Anantapur, 15 June to 30 July for Mahboobnagar and 30 June to 30 July for Junagadh. With these sowing windows, the sowings were delayed by 15, 10 and 8 days as compared to the normal sowings at Anantapur, Mahboobnagar and Junagadh, respectively. For the sowing conditions under climate change, the simulations were carried out for each site for the following agronomic practices.

1. Standard agronomy (SA) of the groundnut crop as described above.
2. SA, except plant population changed to 20 or 30 plants m^{-2}.
3. SA, except nitrogen application at sowing increased to 40 kg ha^{-1}.
4. SA plus surface application of crop residues on the first day of sowing window at 1000 kg ha^{-1} for Anantapur and 1500 kg ha^{-1} each at Mahboobnagar

and Junagadh. These amounts were about 30% of the total dry biomass produced at the sites.

5. SA plus *in-situ* water conservation achieved by reducing the USDA-SCS curve numberby 20 points from the baseline value of each site to enhance infiltration of rainfall into the soil.
6. SA, except that the maturity of the current variety was made shorter by 10% (SHORTVAR) or longer by 10% (LONGVAR) by changing the physiological thermal time of various growth-cycle phases.
7. SA plus 50-mm of supplemental irrigation applied to the crop at pod-filling stage of the crop.
8. SA with multiple combinations of the agronomic practicesas described in 2 to 7 above.

All the simulated data were analyzed using analysis of variance (ANOVA) and the randomized complete block design (RCBD) was followed.Simulation years were considered as blocks, as the groundnut yield in one year under a given treatment were not affected by another year.

RESULTS AND DISCUSSION

Impact of climate change on yield

At Anantapur, the simulated pod yields averaged 1230 kg ha^{-1} under baseline climate (Table 2). Changes in temperature and rainfall (T+R) by 2030 and 2050 time slices significantly ($p<0.05$) decreased the pod yield by 13 and 20%, respectively. The decrease in pod yield in case of T+R+CO_2 ranged from 3 to 4% for the two time slices. At Mahboobnagar, the mean simulated pod yields under baseline climate was 2250 kg ha^{-1}. The change in temperature and rainfall (T +R) significantly ($p<0.05$) decreased the pod yield by 8 and 11% by 2030 and 2050, respectively. In spite of projected increase in rainfall after the month of Juneat Mahboobnagar (Table 1), the reduction in yield under climate change is attributed to the rise in temperature. The effect of T+R+CO_2 on crop yield was positive. The pod yield significantly ($p<0.05$) increased by 5 to 11% for the two time slices. At Junagadh, the mean simulated pod yield was 2230 kg ha^{-1} under baseline climate. At this site the rainfall is projected to decrease during the month of June and substantially increase during later months (Table 1). The changes in temperature and rainfall (T +R) decreased pod yield by 2 and 7% by 2030 and 2050, respectively. With the increase in CO_2concentration (T+R+CO_2) the pod yield significantly ($p<0.05$) increased by 9 to 11% for the 2030 to 2050 time periods, respectively. These results show that, except for the Anantapur site, climate change will have positive effect on the yield of groundnutdespite negative effects of increase in temperature.

Yield response to adaptation options

*Sowing date:*At Anantapur, the mean pod yield of groundnut with normal sowingunder baseline climate was 1230 kg ha^{-1} (Table 3). With climate change by 2050 the pod yield decreased by 4% (1180 kg ha^{-1}). However, the delay in sowing by 15 days under climate change significantly ($p<0.05$) increased pod yield by 18% (1440 kg ha^{-1}), indicating that under future climate the sowing date of groundnut at Anantapur may have to be readjusted to obtain higher yields. With climate change at Mahboobnagar the pod yield significantly ($p<0.05$) increased by 11% above the baseline yield of 2250 kg ha^{-1}. Delay in sowing under climate change further increased the pod yield by 5% (2610 kg ha^{-1}). At Junagadh, most farmers sow the crop by mid-June after the rains have set in. Rainfall is projected to increase with climate change during the crop growing season after June. Climate change significantly ($p<0.05$) increased the pod yield from 2230 kg ha^{-1} to 2480 kg ha^{-1} under normal sowing, which is 11% increase in yield. With the delay in sowingunder climate change the pod yield increased only by 7%. This is attributed to increased crop water stress during the reproductive period (September to October) of the crop with delay in sowing in spite of projected increase in rainfall.

Agronomic practices: Agronomic practices were evaluated for the sowing conditions of the sites that gave the highest increase in yields under climate change, i. e., DS/CC for Anantapur and Mahbhoobnagarand NS/CC for Junagadh (Table 4). At Anantapur, changing plant population, increasing N application, application of crop residues and *in-situ* water conservation practices had insignificant effect on the yield of groundnut with delayed sowing under climate change (Table 4). These results indicate that plant population of 25 plants m^{-2}is good for the future climate at this site. Negligible response to nitrogen application is also expected as the groundnut crop, being a legume, has its own mechanism to fix nitrogen from the atmosphere. Under climate change, a 10% longer maturity variety significantly ($p<0.05$) increased the yield by 9%. Application of one supplemental irrigationduring pod-filling significantly ($p<0.05$) increased the pod yield by 33%. When the promising technologies for the site were considered in combination, the pod yield increased by 52% under climate change. Besides supplemental irrigation, the next significant improvement in pod yield of groundnut occurred with the delay in sowing followed by growing of 10% longer maturity variety (Table 4). It is interpreted from the above that under climate change, the combination of practices including delay in sowing has the potential to increase groundnut productivity by 970 kg ha^{-1} above the simulated baseline yield of 1230 kg ha^{-1}. At Mahboobnagar, the largest gain in yield occurred with the delay in sowing (16%), followed by growing a longer maturity variety (9%), supplemental irrigation (8%) and crop residue application (7%) (Table 4). The yield benefit due to crop residue application could be attributed to the decreased soil evaporation, thus making more water available to the crop. The combined benefit of the promising technologies was 27% increase in yield under the climate change. In terms of yield gain over the mean baseline yield under the current climate (2250 kg ha^{-1}), the combination of practices increased the pod yield by 1060 kg ha^{-1}under climate change with delayed sowing.Junagadh is also a high rainfall site with less rainfall in the months of September and October as compared to other two sites (Table 1). Changing plant population, increasing nitrogen application or changing maturity duration of the cultivar did not affect crop yields under climate change (Table 4). Significant ($p<0.05$) yield gain occurred with supplemental irrigation (6%) followed by crop residue application (4%). The combination of promising agronomic practices increased yield up to 11% under the climate change scenario (Table 4).In terms of absolute yield gain under climate change, the promising agronomic practices increased the yield by 510 kg ha^{-1} over the 2230 kg ha^{-1}obtained with standard practice under the baseline climate.

It is interpreted from the above results that both the impact of climate change on groundnut productivity and response to agronomic management practices will depend upon the current and future agro-climate conditions of the sites. Different combination of practices will be needed to enhance and sustain productivity of groundnut in different environments. Crop response to water management practices (crop residue application, *in-situ* water conservation and supplemental irrigation) can be interpreted in terms of how and to what extent these practices will change the water availability to the crop. Application of crop residues decreases soil evaporation and surface runoff.*In-situ* water conservation decreases surface runoff and increases water stored in the soil profile. When both these practices are combined, more soil water becomesavailable to the crop for its use. Since supplemental irrigation was applied at the critical growth stage of the crop, it was more effective in increasing pod yield than the other two water management practices. The economic benefit of potential technologies and key trade-offs needs to be evaluated before these are adopted by the farmers. For example, in some areas there may be competing demands for the use of crop residues as feed for the livestock or retaining the residues on the field to conserve water or to sustain soil fertility.While these simulation results are specific to the UKMO-HADCM3 GCM model outputs for the SRES A1B scenario, all GCM models predict increase in temperature in future. To that extent the crop simulation responses to rising temperatures and $CO_2$are realistic. Most climate models also predict increased frequency of extreme weather events such as extreme drought or intense rain storms in future. The CROPGRO model for groundnut is currently not sensitive to such extreme weather conditions and needs improvement to enhance its capability for those conditions.

CONCLUSIONS

The study showed that CROPGRO-Groundnut model could be used to quantify the impact of climate change on groundnut productivity in different regions of India. It could also be used to quantify the possible benefits and prioritization of various agronomic adaptation options, individually or in combinations,to enhance and sustain groundnut productivity under climate change.However, the model needs further improvements for simulating groundnut yield responses to extreme weather events such as extreme droughts and water-logging, pests and diseases and nutrients other than nitrogen.

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