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Effect of Drought Stress on Yield Performance of Parental Chickpea Genotypes in Semi-arid Tropics

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Abstract: Chickpea (*Cicer arietinum* L.) is an important cool season food legumes with indeterminate growth habit. The crop is valued for its nutritive seeds and used as animal feed in many developing countries. The productivity of the crop is constrained by several abiotic stresses, among which drought stress is one of the key determinants of crop performance aaccounting for 40-50% yield reduction globally. The present study was conducted to screen, evaluate and select chickpea genotypes possessing high yield potential under drought stress condition at ASALs (arid and semi-arid lands) of Kenya. The experiment was conducted at Chemeron dry land and Eco-tourism Research station, Egerton University and Kenya Agricultural and Livestock Research Institute (KALRO), Pekerra, Marigat, Baringo County. The genotypes were planted in RCBD (randomized complete block design) in three replicates at a spacing of 30 cm × 10 cm, giving a plant density of approximately 25 plants/m^2. Combined analysis of variance revealed existence of highly significant differences among the tested genotypes for most of the agronomic traits. Overall, the highest grain yield was obtained from ICCV 92944 (1,173 kg/ha), ICCV 92318 (1,103 kg/ha) and CAVIR (975 kg/ha), ICCV 92318 (967 kg/ha), ICCV 00108 (956 kg/ha) and ICC 4958 (921 kg/ha): possibly due to its comparatively higher drought (and heat) tolerance, and hence could be used as sources of drought tolerance in further breeding programs. This study was carried out in few drought tolerant sites and further more sites need to be evaluated in addition to other drought and heat screening and optimization of protocols, facilities and analytical approaches to identify better genotypes that respond appropriately to climate change.

Key words: Chickpea, genotypes, drought stress, yield performance and tolerance.

1. Introduction

Chickpea (*Cicer arietinum* L.) is annual crop that belongs to family *leguminaceae*, subfamily *papilionacea* and genus *cic*er [1]. Globally, chickpea has consistently maintained a much more significant status among world pulses, ranking second in area of production (15.3%) after common bean and third in production (14.6%) after common bean (*Phaseolus vulgaris* L.) and field pea (*Pisum sativum* L.) [2-6]. Chickpea is one of the nutrient-rich semi-arid tropical legume crops grown mostly in cool season in Asia, USA, Australia, Middle East and Eastern and Southern Africa. It is cultivated in over 60 countries and traded in over 190 countries, as second most important legume after dry beans in the world in terms of production and consumption [7]. Though, chickpea is a relatively a new crop in Kenya, it has a potential production of 0.29-3.5 ton/ha [8-11]. However, there are major production constraints which limit chickpea production globally and they include narrow genetic diversity of cultivated chickpea, biotic (pod borer, fusarium wilt, and ascochyta blight) and abiotic (drought, heat, cold and salinity) stresses [12, 13]. The crop faces various abiotic stresses among which drought stress is progressively posing major production constraint in arid areas short-season environments. In Kenya, drought is the leading crop production constraint in the dry lands (ASALs) causing frequent crop failures and famine. In Kenya drought stress causes 30-45% yield reduction of major crops like maize, beans, wheat and even chickpea

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annually in marginal areas of Kenya during drought periods [13]. Global chickpea production losses due to abiotic stresses (mainly drought, salinity, low temperature and heat stress) have been estimated to be approximately 3.7 metric tons, amounting to average losses of 40-60% [14]. Among these environmental stresses, drought is the most important constraint accounting for 40-50% yield reduction globally [14, 15]. This has contributed to yield stagnation at below 1 ton/ha for the past 2-3 decades globally [16]. Supplementation of the water deficit by irrigation is not feasible in these areas due to its scarcity. Furthermore, in areas where water is supplied by rivers and/or streams, there is competition from animals and human for domestic use. Establishment of irrigation schemes needs for large capital outlay for effective coverage.

Drought often occurs in combination with high solar irradiance, high temperature, porous sandy soils and strong wind, all of which can aggravate plant injury during critical stages mainly reproductive stages. Drought stress and high temperature during the grain filling period can reduce the individual seed size as it might interfere with assimilate translocation period to sink at maturity which may lower grain yield per plant [17]. Grain yield was reduced by 53-330 kg/ha for every 1 ℃ seasonal temperature rise in India [18].

Previous chickpea improvement efforts by Egerton University and Kenya Agricultural and Livestock Research Institute (KALRO) focused on developing high yielding and drought tolerant varieties. As a result, about seven improved chickpea varieties for increased yield were released some of which are currently under cultivation [19, 20]. However, their drought tolerance levels in drought and high temperature (heat) stress conditions (like Baringo county the trial site) are not well documented, though global warming which is on alert and some signals are evidenced in Kenya, at national level. Furthermore the communities living in these regions are neither thematized for climate change impacts nor are making efforts being attempted by the national chickpea improvement program to focus on combined heat and drought tolerance. Therefore, the objective of this experiment is to assess variability among genotypes for tolerant, (high temperature indirectly) and high potential yield under ASALs and thermal zone of Kenya by screening in drought and heat hot spot locations of Chemeron and Marigat. Thus, screening of chickpea germplasm in right drought and heat hot spot location could also provide information of traits for selection of best plant material and therefore, assist in future breeding strategies [21]. In addition, Ref. [22] reported that traits with positive and significant correlation with seed yield can be used for indirect selection of high yielding genotypes. Therefore, the objective of this experiment was to assess variability among genotypes for drought tolerant (and indirectly heat) and high potential yield under in hot spot location.

2. Materials and Method

2.1 Experimental Sites

The study was conducted at two sites, KALRO (Kenya Agricultural Livestock and Research Organization), Pekerra, Marigat and DARTEC (Dry land Research Training and Ecotourism Centre), Chemeron. The two sites are located in Marigat Division, Baringo County in the lower midland agro-ecological zone (LMV) with low agricultural potential. KALRO Pekerra-Marigat lies at a latitude of 1°45´ N and longitude 36°15´ E with an altitude 1,067 m. a.s.l. Both sites have higher mean maximum, mean minimum and extreme maximum temperatures are: 24.6, 32.4, 16.8, and 37.7 ^{o}C, respectively [23]. The area receives between 700 mm and 950 mm of rainfall per annum, with peaks in the April/May and July/August rain seasons. The soils are volcanic fluvisols of sandy/silty clay loam texture, slightly acid to slightly alkaline, highly fertile with adequate, potassium, phosphorus, calcium, magnesium but low nitrogen and carbon. Annual rainfall mean is 654 mm and ET (evapo-transpiration) is 1,360 mm [24]. DARTEC, Chemeron and Kenya Agricultural Research Institute (KALRO-Pekerra) are located in Marigat Division, Baringo County in the lower midland agro-ecological zone (LMV), at an altitude of 1,080 m, above sea level [25].

2.2 Plant Materials and Experimental Details

The experiment conducted in both sites (Marigat and Chemeron) was under rainfed conditions during the long rains (July/September 2013/2014 seasons). A second experiment was conducted during short rains under supplemental irrigation (Nov 2013/Jan 2014 season). Trial one was planted in RCBD (randomized complete block design) in three replicates at a while trial tow that was planted as split plot where supplemental irrigation was main plot while genotypes was subplot. Spacing of 30 cm between rows and 10 cm between plants was used and harvesting was done from two central rows of each plot (2.4 m^2). The crops were routinely sprayed with insecticide to prevent damage from *Helicoverpa armigera*. Weeds were mechanically controlled every one week. The genotypes evaluated included three advanced lines, commercial checks released in Kenya, drought tolerant check (with high root length), two drought susceptible check and a Spanish variety as shown in Table 1.

2.3 Data Taken

This study used measure of plant growth and yield traits at different developmental stages of chickpea as tools for drought (and heat) tolerance screening. These include plant height, 100-seed weight (g), biomass yield (g one meter $plot^{-1}$) (as the weight of above ground shoot), plant height (cm) (measured at maturity from the base of the plant to the top of the main shoot from 5 randomly selected plants), canopy diameter (cm), HI (harvest index) = seed yield/biological yield + grain yield (recorded as grain yield from 1 meter plot after harvesting, then dried to 13% moisture content and converted to kg/ha). Grain yield was collected from two central rows of each plot (2.4 m^2) and the aerial parts of the plants from 2 central rows were air dried at 38 °C for 48 h to determine shoot dry weight.

2.4 Data Analysis

Data analysis was performed by GenStat (14th edition) statistical software. The means were separated by least significant difference at $p < 0.05$.

3. Results

3.1 Phenotypic and Genotypic Variations in Trial Sites

Results from combined analysis of variance revealed that there were significant genotypic differences among the tested chickpea genotypes for most of the traits

Table 1 List of plant materials (genotypes) used in experiment.

Genotype	Type	Status
ICCV 97105	Desi	Commercial check-Egerton Chania Desi 1
ICCV 00108)	Desi	Commercial check -Leldet 068
ICCV 92944	Desi	Commercial check-Egerton Chania Desi 2
ICCV 92318	Kabuli	Advanced breeding lines
ICC 4958	Desi	Drought tolerant check (high root length)
ICCV 97306	Kabuli	Advanced breeding lines
ICC 3325	Desi	Breeding line
ICC 283	Desi	Susceptible breeding line
ICC 1882	Kabuli	Susceptible line (low root length)
Ngara local	Desi	Tolerant local accession
CAVIR	Kabuli	Spanish Tolerant variety

Table 2 Analysis of variance for sum of squares of chickpea traits grown under drought stress under rainfed condition in Marigat and Chemeron, Baringo county 2013/2014 season.

Source of variation	d.f	Biomass (kg/ha)	Canopy spread	Plant height (cm)	Harvest index	100 seed weight (g)	Yield (kg/ha)
Genotype	10	3,374,033***	353.41*	178.22**	0.046***	285.85***	393,961***
Site	1	1,727,621***	990.44**	961.89**	0.00	133.26***	284,610**
Genotype × site interaction	10	22,181**	7.52***	16.88***	0.00	1.88**	2,590
Error	42	10,680	1.722	4.531	0.004	0.87	50,093
Total	63						
CV%		5.2	2.9	5.2	22	5.3	27.6
$l.s.d._{0.05}G$		120.4	1.53	2.48	0.07	1.09	260.8
$l.s.d._{0.05}S$		51.3	0.65	1.058	0.03	0.46	111.2
$l.s.d._{0.05}G.S$		170.3	2.16	3.507	0.11	1.54	368.8

Key: G-Genotype, S-site G.S-Genotype x season interaction, *, **, ***- $p < 0.1$, 0.05 and 0.001 significance levels respectively.

considered in this study (Table 2). There were significant differences ($p < 0.05$) in the genotype, site and genotype × site interaction among the trait indicating that there were variations in test genotypes and traits tested (Table 2). The mean above ground biomass in Chemeron (1.788 kg/ha) was 13% lower than Marigat (2,060 kg/ha), but ranged from 1,107 kg/ha (ICC 1882) in Chemeron to 3,003 kg/ha (ICCV 92318) in Marigat (Tables 2 and 3).

On average, commercial checks (Egerton Chania Desi 1, Egerton Desi 2 and LTD 068) had a lower mean (1,781 kg/ha) in Chemeron compared to drought tolerant check (ICC 4958) that recorded 2,114 kg/ha. In Marigat commercial checks similarly had a lower mean (1,899 kg/ha) as compared to drought tolerant check (ICC 4958) that recorded 2,487 kg/ha (Table 3).

CS (canopy spread) was measured as indicator of moisture conservation trait in drylands since larger canopies tend to offer better cooling effects due to reduced surface ETs. In Chemeron CS ranged from 28 cm (ICC 3325) to 50 cm (ICC 4958 and ICCV 92318) as compared to 32 cm (IC3325) to 60 cm (ICC 4958) with mean of 18% higher in Marigat than Chemeron (Table 3). On average, Marigat had a higher mean (48.9 cm) compared to that recorded in Chemeron (41 cm) (Table 3). Drought tolerant check (ICC 4958) had 28% and 41% higher than drought susceptible checks (ICC 283 and ICC 1882) in Chemeron and Marigat, respectively (Table 3). There was however no significant difference in CS for commercial checks, Spanish variety (CAVIR) and advanced breeding lines (ICCV 92318 and ICCV 97306) (Table 3).

Plant height ranged from 28.6 cm (ICC 283) to 45.5 cm (CAVOR) in Chemeron to 35.08 cm for ICC 283 to 53 cm for CAVIR, ICCV 92318 and ICCV 01008 (Table 2). Overall plants were 17% taller in Marigat than Chemeron, but there was significant variation within test genotypes. Commercial varieties were taller both tolerant check (ICC 4958) and susceptible checks. There was significant inherent variation among the chickpea genotypes observed for HI 100 seed weight and yield for sites whereas, sites and GXE (genotype × environment) interaction exhibited non-significant differences (Tables 2 and 3). HI ranged from 0.40 (ICC 1882) to 0.62 (ICCV 97105) followed by Ngara local (0.58), ICCV 92944 (0.58) (Table 2). On average, Marigat had 4.5% higher HI than Chemeron, with limited G × S interactions. There was no significant difference in HI of drought tolerant check (ICC 4958) in both sites, while there was a decrease in HI for some genotypes like ICCV 97105 in Marigat. Susceptible checks, ICC 283 and ICC 1882 also had no change in HI in both sites (Tables 2 and 3). Ngara local also had a slight decline in HI in Marigat than Chemeron. The result of this study also showed there were highly significant differences ($p < 0.05$) in 100 seed weight (Tables 2 and 3). Maximum hundred seed weight was observed in the Kabuli types ICCV 92318

Table 3 Mean performances for yield and yield components of chickpea genotypes grown under drought stress under rainfed conditions in Marigat and Chemeron in the 2013 and 2014 seasons.

Variety	Biomass (kg/ha)	Canopy spread (cm)	Plant height (cm)	Harvest index	100 seed weight (g)	Yield (kg/ha)
Chemeron						
ICCV 92318	2,553	49.76	44.94	0.41	26.78	1,014
CAVIR	1,992	44.76	45.55	0.46	23.49	920
ICCV 97306	1,817	46.69	40.03	0.49	22.6	890
ICC 4958	2,114	50.32	38.19	0.40	20.33	846
ICCV 92944	1,882	40.38	36.69	0.58	18.39	1,089
ICCV 00108	2,037	45.3	35.89	0.44	15.65	901
Ngara local	1,560	34.46	38.07	0.58	12.53	904
ICCV 97105	1,423	39.1	35.88	0.62	14.91	889
ICC 283	1,404	34.78	28.65	0.43	10.53	598
ICC 1882	1,107	37.68	35.25	0.40	9.53	455
ICC 3325	1,781	28.21	31.16	0.44	8.40	789
Mean	1,788.2	41.0	37.3	0.44	16.6	845.0
Marigat						
ICCV 92318	3,003	58.62	53.03	0.40	31.5	1,192
CAVIR	1,756	52.41	53.9	0.59	27.64	1,029
ICCV 97306	2,137	53.04	44.85	0.49	26.59	1,047
ICC 4958	2,487	60.02	44.98	0.40	23.92	995
ICCV 92944	2,408	47.18	43.15	0.52	19.28	1,258
ICCV 00108	2,397	55.6	53.22	0.42	18.41	1,011
Ngara local	1,789	40.32	45.05	0.54	14.74	969
ICCV 97105	1,792	51.22	42.25	0.58	18.83	1,043
ICC 283	1,504	41.05	35.08	0.42	12.39	639
ICC 1882	1,303	44.38	41.65	0.41	11.21	535
ICC 3325	2,095	32.83	37.13	0.40	9.88	828
Mean	2,061.0	48.8	44.9	0.46	19.5	958.7
CV%	5.20	2.90	5.2	22.00	5.30	27.60
l.s.d.0.05 G	**	ns	*	*	*	***
l.s.d.0.05 S	*	ns	*	ns	*	**
l.s.d.0.05 G.S	**	*	*	ns	*	**

G-Genotype; S-Site; G.S: Genotype × Site interaction, *, **, ***-p < 0.1. 0.05, 0.001 significance levels respectively.

and CAVIR in both sites (Table 2), while the lowest hundred seed weight was recorded from the standard checks ICC 283 and ICC 1882 in both Chemeron and Marigat (10 gm and 11.5 gm, respectively). Most Desi genotypes had lower seed weight in both sites. On average, Marigat had a higher mean (19.5 gm) compared to that recorded in Chemeron (17.6 gm) (Tables 3). Drought tolerant check (ICC 4958) had 51% and 49% heavier seeds than drought susceptible checks (ICC 283 and ICC 1882) in Chemeron than in Marigat (Table 3).

Results of grain yield performance showed that there were highly significant differences ($p < 0.01$) in grain yield among chickpea genotypes in both sites (Tables 2 and 3). Overall, the highest grain yield was obtained from ICCV 92944 (1,173kg/ha), ICCV 92318 (1,103 kg/ha) and CAVIR (975 kg/ha), ICCV 92318 (967 kg/ha), ICCV 00108 (956 kg/ha) and ICC 4958 (921 kg/ha). The lowest grain yield was obtained from the susceptible check ICC 1882 (495 kg/ha) followed by ICC 283 (618 kg/ha) and ICC 3325 (808 kg/ha). Marigat had 12% higher yield than Chemeron, which ranged from 455-598 kg/ha (ICC 1882 and ICC 283) in Chemeron to 1,192-1,258 kg/ha (ICCV 02318 and ICCV 92944) in Marigat (Table 3). Commercial checks (ICCV 92318, ICCV 92944, ICCV 97105, ICCV 00108) had 11% and 9% higher yield than tolerant check (ICC 4958) in Chemeron as compared to Marigat. Similarly, commercial checks had 45% and 47% higher than mean of susceptible check (ICC 1882, ICC 283) in Chemeron and Marigat respectively (Table 3). Similarly drought tolerant check (ICC 4958) had 37% and 42% higher grain yield than mean yields of drought susceptible checks (ICC 283 and ICC 1882) (Table 3). In both sites combined, commercial checks had 45% higher yield (1,032 kg/ha) than susceptible checks (ICC 1882, ICC 283) (567 kg/ha).

4. Discussion

In this study, the effect of more intense stress condition in Chemeron as compared to Marigat and their interaction with genotypes portrayed some level of significance in genotypes studies and all studied traits. During the growing period there was rapid increment in drought stress and temperature, which might have posed greater factor of yield reduction, possibly from physiological interference beyond osmotic adjustment, in the first trial site than the second. In this study, the average grain yield of chickpea genotypes reduced by 12% in Chemeron (845 kg/ha) as compared to Marigat (958 kg/ha) (Table 3). Similarly [26, 27] report that peak photosynthetic rate was observed at 22 ^{o}C in chickpea, but the net photosynthetic rate showed to be reduced at 28 ℃ with increasing drought stress. Also, Ref. [28] noted that the ability of chickpea to perform better under drought stress conditions may be attributed to osmotic adjustment while Ref. [29] reported that under severe drought, pearl millet utilizes osmotic regulation for the maintenance of cell turgor for survival or for assisting in plant growth. Thus, observations in the present study suggested that, the two experimental locations are suitable site for screening drought (and heat) stress tolerance of chickpea and the performance of genotypes to the existing drought would result in screening and identification of genotypes tolerant to drought stress.

There was a reduction in the mean aboveground biomass by 13% between the two sites (Chemeron (1,788 kg/ha); Marigat (2,060 kg/ha)). These findings are in agreement with those earlier reported by Ref. [30] who noted that decreased fresh and dry biomass production is the most common adverse effect of water stress. Drought stress reduced plant height by 17%, Chemeron than Marigat with significant variation within test genotypes. Commercial varieties were taller both tolerant check (ICC 4958) and susceptible checks. There was significant inherent variation among the chickpea genotypes observed for HI, 100 seed weight and yield. Similarly, Ref. [31] and [32] noted that there were decreases in dry matter production, plant height, and seed yield under drought stress. Similar results were reported by Ref. [33] in common bean subjected to drought and observed that overall yield reductions due to drought treatments were greater in the drought-susceptible cultivars than in the tolerant cultivars. Also leaf area index, leaf dry weight, shoot dry weight, and root dry weight decreased under drought stress, as compared to non-stress conditions [34]. The “balanced growth” hypothesis suggests that some plants respond to drought by stimulating or maintaining root growth while reducing shoot growth.

HI had low variation in the two sites, but was significant among the genotypes in each site. Similarly, Ref. [35] noted that 100-seed weight exerts maximum positive indirect effect on biological yield per plant and harvest index. They further suggested that selection for seed number and seed weight together would undoubtedly culminate significant improvement in yield potential of chickpea. Studies of the trends of these traits in contrasting genotypes showed that they could easily distinguish genotypes in different drought tolerance groups. Therefore, these traits should be taken into account when selecting genotypes under drought conditions.

The results showed there were highly significant differences in grain yield among chickpea genotypes in both sites (Tables 2 and 3). Overall, the highest grain yield was obtained from ICCV 92944 (1,173 kg/ha), ICCV 92318 (1,103 kg/ha) and Cavir (975 kg/ha), ICCV 92318 (967 kg/ha), ICCV 00108 (956 kg/ha) and ICC 4958 (921 kg/ha). Overall, one line (ICCV 92318) out of 10 genotypes, achieved significantly higher mean yield level than the best yielding standard checks (ICCV 97105, ICCV 00108 and ICCV 92944) (mean 1,035 kg/ha) in both sites. This significant grain yield increment in this genotype is due to its comparatively higher drought (and heat) tolerance and therefore we can use it as source of drought tolerance in further breeding activities. Overall variety ICCV 92944 had highest yield across sites. It was also indicated that the top two high yielding chickpea genotypes are Desi types which achieved significantly higher yield level than kabuli type's chickpea genotypes (Table 2). In related study Refs. [36, 37] confirmed that Desi chickpea types were high yielders, better in biomass rate and harvest index over kabuli types of chickpeas, which could come from inherent variability in the two types. The lowest grain yield was obtained from the susceptible kabuli check ICC 1882 (495 kg/ha) followed by ICC 283 (618 kg/ha) and ICC 3325 (808 kg/ha). The higher yields study confirms earlier studies that genotype ICCV 92944 could be possessing both drought and heat tolerance mechanism as earlier reported by Ref. [38] who noted that pollen from the genotype ICCV 92944 were fertile at 35/20 ℃ day/night exposure for 24 h before anthesis while those of genotype ICC 5912 became sterile. Furthermore, Ref. [39] noted that high temperature effects on pre-anthesis are related to anther development, pollen sterility and pollen production and pollen sterility is one of the key factors limiting legume yield under high temperature and drought stress. These findings showed that it is also possible to predict genetic variation among genotypes for reproductive phase heat tolerance using reproductive and phenotypic traits.

Commercial checks (ICCV 92318, ICCV 92944, ICCV 97105, ICCV 00108) had 11% and 9% higher yield than tolerant check (ICC 4958) in Chemeron as compared to Marigat. Similarly, commercial checks had 45% and 47% higher than mean of susceptible check (ICC1882, 283) in Chemeron and Marigat respectively (Table 3). These genotypes had both higher HI, and 100 seed weight in both sites in which three Desi varieties (ICCV 92944, ICCV 97105, ICCV 00108) where Desi while ICCV 92381 was kabuli genotype. The standard tolerant check ICC 4958 is also Desi. Similar findings have also been reported that Desi chickpea types were high yielders, better in biomass rate and harvest index over kabuli types of chickpeas, which could come from inherent variability in the two types [40-43].

5. Conclusions

The findings of this study showed that combined analysis of variance was significant among the tested genotypes for most of the traits considered, indicating the existence of variability among tested genotypes and the potential for selection under drought (and heat) stress environments. The overall mean values of germplasms revealed that all of the test genotypes produced less aboveground biomass under higher drought stress in Chemeron than Marigat. Though there was no statistically marked difference among the genotypes in their HI, almost all the tested genotypes produced more HI under less drought stress. Highly significant variation among the chickpea genotypes was observed for number of 100 seed weight, plant height, grain yield, and biomass yield. The top 3 best responding genotypes under drought (and heat) stressed environment were ICCV 92944, ICCV 97105, ICCV 00108 and standard check (ICC 4958). These drought tolerant chickpea genotypes could further utilized in breeding advance as source parents. Genotype ICCV 92318 was best yielding kabuli followed by Cavir and ICCV 97306 and could be advanced for possible release as commercial varieties in low stress environments. The findings also indicate that the top 3 high yielding chickpea genotypes are Desi types suggesting that, Desi types inherent genetic ability to tolerate drought is better compared to kabuli types. This study was carried out in few drought tolerant sites in Kenya and further more sites need to be evaluated in addition to other drought and heat screening and optimization of protocols, facilities and analytical approaches to respond appropriately to climate change.

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