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ORIGINAL ARTICLES

A Simulation of Two Different Sets of Wheat Genotypes Under Semi Arid Climate by Using A Crop Model

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ABSTRACT

The present study was conducted in the eastern high plateaus of Algeria under semi-arid climate, typical of durum wheat cultivation; the aim of this work was to assess drought tolerance and yield response to water stress of durum wheat genotypes. The study consisted of two sets of eight genotypes including two local Algerian cultivars and six advanced lines from the CIMMYT/ICARDA breeding program. Both of genotypes sets were cultivated under rainfed conditions and closely monitored on field to be simulated by *BUDGET* software. The simulated values of soil water contents were highly correlated with observed values (r=0.76); Relative yield for improved genotypes was more sensitive of 55%, Relative yield of local genotypes has reached 70% so, reducing Evapotranspiration affected more yields of improved genotypes. Local genotypes were less exposed to stress period but more subjected to terminal stress, however improved genotypes have suffered more stress period but they have managed to escape terminal stress, this have had a good impact on their grain yield (76.46q/ha) and Water Use Efficiency (14.50 kg/ha/mm) against 49.75q/ha of grain yield and 10.12kg/ha/mm of Water use efficiency for local genotypes.

Key words: Simulation, Wheat genotypes, *BUDGET* software, water stress.

Introduction

Drought extends over several million hectares worldwide. It is defined as a lack of water in the plant environment that has the power to reduce crop yields (Cooper *et a*l., 2009). When this deficit occurs before the completion of crop growth, it may reduce crop development. The negative impact of the drought depends mainly on the vegetative stage, the duration and intensity of stress. The fundamental problem of selection for drought tolerance is two-sided: first it must take into account the complexity of the phenomenon of water stress makes it difficult to define the ideal genotype for drought tolerance (Ribaut *et al.* 2004), and secondly, the complex responses of plants that are dependent stages of development and the type of stress toward the lower water potential. Until now, it was impossible to determine the key process tolerance (Bartels and Sunkar, 2005). Mediterranean climate characterized by hot and dry long summers, winters are short, mild and wet (Aschmann, 1973) and considered as the traditional durum wheat climate where water stress is a major constraint to crop development (Siman *et al*., 1993). In Algeria, according to *Ciheam* report, the average yield of cereals in 2004 was almost 200% of that in 1991-2000 crop year, however, a negative growth rate of less than 6% was recording when compared to 2003 (Badrani, 2006), this is largely explained by inter-annual fluctuations in rainfall. Crop models, were developed for several years to provide a conceptual framework for the study of dynamic interactions between plants, soil, climate and cultivation techniques at field scale. (Brisson *et al*., 1998, 2002), they also reported that since the first test model of de Wit (1965), crop models are extended affecting a large part of cultures and providing a tool for reflection on the relationship between crops and environment. However, most of the modeling efforts focused on field crops, trying to predict the yield on the basis of climatic and soil conditions (Heinmann *et al*., 2002). Or by identifying intrinsic characteristics of each genotype relating to its interaction with particular environmental conditions, which requires the development of models able to identify these variables and to simulate the behavior of genotypes in a broad range of environments (Tardieu, 2003; Yin *et al*., 2003; Reymond *et al*., 2004; Cooper *et al*., 2009; Sinclair *et al*.,2010).

Our study aims to simulate a collected eight durum wheat genotypes vegetative growth, one set from a local genotypes and the other one from improved selection genotypes (CIMMYT / ICARDA); These genotypes will be closely monitored at field scale to obtain the maximum empirical data for the crop and its environment, in order to use as a software BUDGET (Raes 2002) inputs, which will be the simulation tool in this work. This model has been tested and validated before in other Mediterranean areas. The use of *BUDGET* software as a first once on durum wheat crop under local environmental conditions in relation to the crop development stage

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can contributes to assess some of other indices such as crop water stress, root zone depletion, Water stress period and expected relative crop yield, which can provide a better understanding of the varietal behavior in such environmental conditions, also, they can contribute to the selection process for the determination of more tolerant genotypes to water stress.

Materials and Methods

1- The experimental site :

The experiment was conducted in a farm located in Ain Abessa Municipality (N: 36 ° 18', E 5 ° 18') in eastern of Algeria during the 2006-2007 crop year. The climate is upper semi-arid. This climate is characterized by warm winds and dry summer temperatures around 35 ° C (Bechtel, 1975) and most of the precipitations (400-500mm per year) fall during the winter months despite a small portion which spread over the remaining period of the season. The Soil is colluvial relatively deep with a black color, a slight slope, and clay-loam texture (Duchauffour, 1977).

2- Plant Material and simulation tools.

2-1 Plant Material:

The plant material consisted in eight durum wheat genotypes, six varieties were introducing from a CIMMYT / ICARDA selection, the rest was two local varieties (Table 1), these genotypes are different in terms of yield potential and earliness.

Table 1: Origins of the studied genotypes.

Genotype	Origin
Altar	CIMMYT cultivar, released in 1984
Dukem	CIMMYT advanced line
Sooty	CIMMYT advanced line
Kucuk	CIMMYT cultivar, released in 1984
Waha	CIMMYT/ICARDA released in Algeria in 1986
Mexicali	CIMMYT/ICARDA cultivar, released in 1975
Polonicum	Local genotype
Oued zenati	Local genotype

2-2 Simulation Tools : “BUDGET software »

Developed by the Water Resources Engineering staff belonging to one of The Inter Universitary Programme in Belgium: http://www.iupware.be.

BUDGET software is composed of a set of validated subroutines describing the various processes involved in water extraction by plant roots and water movement in the soil profile. During periods of crop water stress the resulting yield depression is estimated by means of yield response factors.

However, The reference Evapotranspiration “ETo” from daily meteorological data was assessed in the ETo calculator software, by means of the FAO Penman-Monteith equation (1990). This method has been developed and selected by FAO as the reference, is physically based, and explicitly incorporates both physiological and aerodynamic parameters.

3- Experimental design and monitoring:

The experiment has been conducted in a randomized complete block design (RBCD), where each genotype was repeated three replications. Four stations of one meter per plot were randomly selected within the 24 plots of 1.8m² (2.5m by 0.72m) spaced 18 cm. sowing was done manually in December 22th, 2006. Density was set at 417 grain / m², and adjusted after total emergence to 335 plants/ m². At sowing, an application of basal dressing (TSP) of 1q/ha, however, a second dose of 0.8 q/ha of nitrogen fertilizer (urea) was applied during early tillering.

4- Measures and notations:

4-1 Rainfall and temperatures:

Daily rainfall, minimum and maximum temperatures were recorded at a meteorological station near the experimental site.

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4-2 Soil moisture:

Throughout the vegetative cycle, soil sampling was done by decade using a soil auger instrument to a depth of 1 meter. For each sampling, five soil samples are collected each 20cm of depth. The samples were weighed fresh and passed in an oven at 85°C for 48h to determine soil moisture content (Melling *et al*, 2005)

4-3 phonological stages:

Monitoring on field focused on notation of the phenological stages, namely: emergence, heading, flowering and ripening.

5- Optimal setting of BUDGET software:

To approximate actual conditions, software configuration has been fully optimized on the basis of Climate/Crop/Soil continuum.

5-1 Inputs of BUDGET software:

The input of *BUDGET* consists of:

5-1-1. Daily Climatic data:

Consist of daily notations of rainfall and reference evapotranspiration (ETo) calculated by *ETo Calculator* software by using the Penman Monteith equation (FAO)

5-1-2. Crop parameters:

Parameters describing crop development and root water uptake have been parameterized as follows:
- Class of Crop type has been set to Winter wheat under rainfall conditions
- Class of rooting depth; was set at 1.7m depth for local genotypes and 1.2m for improved ones
- Class of sensitivity to water stress was parameterized to moderately tolerant to water stress with at **p**=0.55 for local genotypes, and to moderately sensitive at **p**=0.4 for local genotypes. Where **p** is the soil water depletion fraction for no-stress.
- Class of mulch surface was set at 0% because of the conventional tillage and manual weeding during the vegetative cycle.
- Specifying the total length of growing period was configured to 199 days for local genotypes and 193 days for improved genotypes
- The crop coefficient (Kc) is an essential component for the calculation of Evapotranspiration “ET”. It takes into account the type of crop and stage of development. The calibration of Kc was maintained at 1.15 for mid stage and 0.25 at late stage for both local and improved genotypes.

5-1-3. Soil parameters:

The soil profile may be composed of several soil layers, each with their specific characteristics. In our case the soil texture was parameterized as clay-loam with one layer of 2m depth. Root extraction subroutine is assumed linearly regressive with of 40%, 30%, 20% and 10% according to depths from 0 to 25 cm, 25-50 cm, 50-75 cm and 75 to 100 cm, respectively with the root zone

5-2 Output:

By a given initial conditions, *BUDGET* simulates the solute transport and water uptake in the specified Climate/Crop/Soil environment. During the simulation the variation of the soil water content is displayed at the end of each day of the simulation period. At the end of the simulation process, *BUDGET* displays the total value for each of the parameters of the soil water balance, the daily root zone depletion and the expected relative crop yield.

Results and Discussion

1- Water soil content simulation:

A significant correlation was observed between soil moisture simulated values and observed values in the overall layers. *Pearson* coefficient of correlation was calculated to assess the relevance of the model in predicting soil moisture at each layer during 17 decades. Correlations were too high, exceeding the threshold of significance (5%), which says that the model performs well in simulating soil moisture (Table 2).

The usefulness of soil moisture simulation during the growing cycle is to predict water stress periods, in order to overcome them by providing irrigation water to optimal quantities, since it is directly related to the soil water status and the stresses acting on the vegetative growth.

Table 2: Correlation between simulated and observed soil water content in the sampled depths.

Soil depth	Coefficient of Correlation "r" (n=17)
0cm to 20cm	0.78
20cm to 40cm	0.77
40cm to 60cm	0.79
60cm to 80cm	0.79
80cm to 100cm	0.67

2- Assessment of Water stress:

FAO research paper 33 on yield response to water (Doorenbos and Kassam, 1979) provided a simple method to assess the impact of crop water stress on yield reduction for more than 25 crops. Water stress is determined as the difference between the actual Evapotranspiration (*ETact*) and the Evapotranspiration when crop requirements are met (*ETmax*). These are linearly related to crop yield (*Yact*) under certain conditions, and maximum yields (*Ymax*) under optimal conditions (Stewart et al., 1977)

$$\mathbf{1-\frac{Ya}{Yx}=Ky\left[1-\frac{ET\,a}{ET\,x}\right]}$$

Where *Yx* and *Ya* are the maximum and actual yields, $\frac{Ya}{Yx}$ is the relative yield, $1-\frac{Ya}{Yx}$ is the reduction in relative yield

ETx and *ETa* are the maximum and actual Evapotranspiration, $\frac{ET\,a}{ET\,x}$ is the relative Evapotranpiration, $1-\frac{ET\,a}{ET\,x}$ is the relative Evapotranspiration deficit or water stress.

K_y is a yield response factor representing the effect of a reduction in Evapotranspiration on yield losses. However, *ETmax* and *Ymax* are difficult to estimate under actual field conditions. In many publications, *ETmax* is considered equal to the potential Evapotranspiration (*ETp*), whereas *Ymax* is usually considered as the maximum yield obtained in an experimental set-up.

Table 3: Phenological stages and assessment of water stress.

Genotype	Date of emergence	Date of flowering	Date of maturation	Beginning of water stress period	water stress $1-\frac{ET\,a}{ET\,x}$
Local	13-01	27/05	01/07	01/06	0.37
Improved	14/01	21/05	27/06	23/05	0.33

Indeed, positive values of water stress $(1-\frac{ET\,a}{ET\,x})$ calculated on the basis of potential and actual Evapotranspiration (Wellens 2004) were observed from the beginning of the flowering stage. Water stress started from May 23rd for improved genotypes, however, it was observed 09 days later for local genotypes (fig 1). In addition to high Evapotranspiration demands, cereal crops suffer additional abiotic stresses such as winter-spring cold and terminal heat (Hafsi *et al* 2009). Where mean temperatures have averaged 30°C during grain filling, which will affect the grain yield. Previous studies of the effect of heat stress on wheat growth have estimated that yields were reduced by 18-35% for 35°C heat stress imposed over a single day (Alexander *et al.* 2010; Talukder *et al.* 2010)

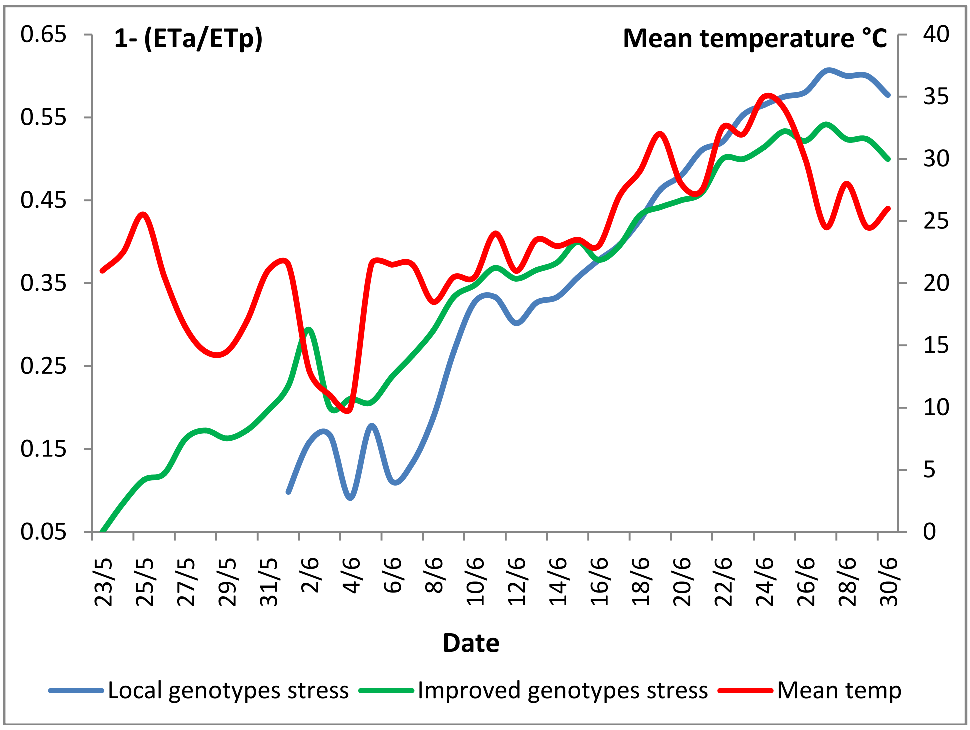

Fig. 1: Relationship between water stress and mean temperature elevation.

Water content in the root zone can be expressed by the root zone depletion "D_r", i.e., water shortage relative to field capacity "FC". At field capacity "D_r" becomes null. When soil water is extracted by Evapotranspiration "ET", the depletion increases and stress will be induced when "D_r" becomes equal to Readily Available Water "RAW". After the root zone depletion exceeds RAW, the root zone depletion is high enough to limit "ET" to less than potential values and the crop ET begins to decrease in proportion to the amount of water remaining in the root zone. The starting date of water stress also coincides with the effective dates of flowering of improved genotypes and continues until the end of the growth cycle, causing water and heat stress of 40 days (Fig 2), which will have repercussions on the rate of grain filling and decreasing the stay-green period. The period of water stress defined by the intersection of the curve of the Root zone depletion "D_r" with the Readily Available Water curve, begins at the Anthesis stage and continues until the end of the cycle.

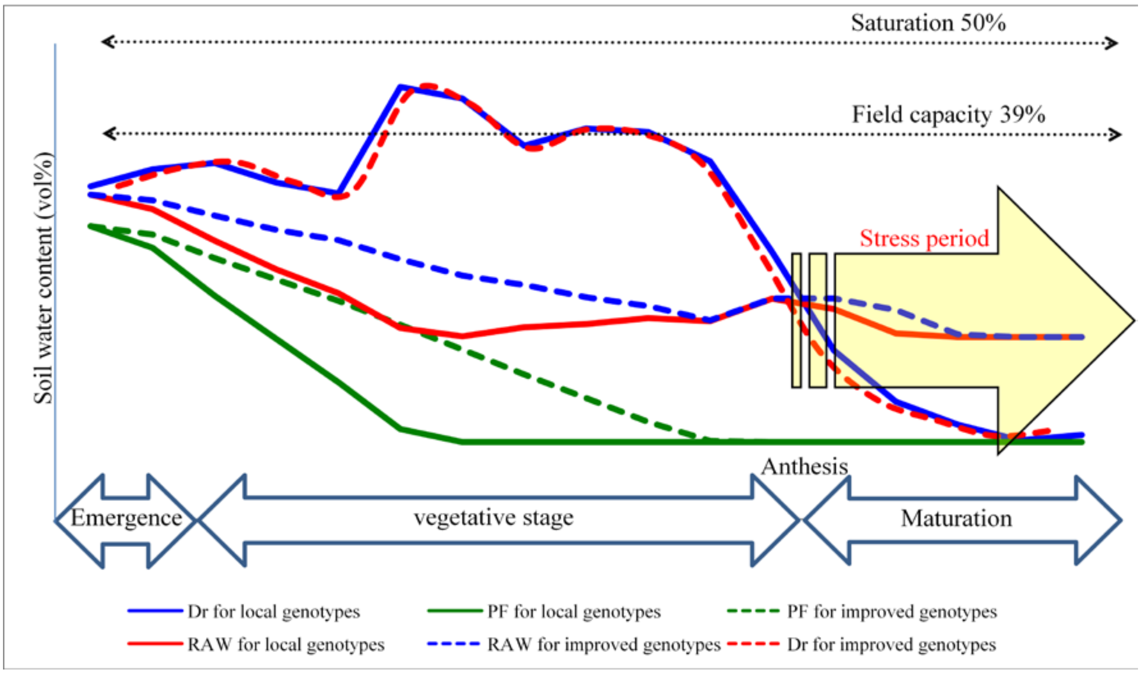

Fig. 2: Root zone depletion in the soil profile for both local and improved genotypes.

3- Assessment of expected relative yield:

The yield response factor Ky according to Doorenbos and Kassam, (1979) was used as we have already mentioned. Using a polynomial function (Kipkorir et al., 2002), Ky values are converted to sensitivity indices for the multiplicative model of Jensen (1968). Using procedure of Tsakiris (1982), the effect of water stress on relative yield for a short period of time is derived from the relative ET using the empirical model of Jensen (1968).

BUDGET also functions as a predictive model of relative yield. During periods of water stress, losses of crops are estimated using (K_y). BUDGET provided declining of relative yields of the genotypes sets from the beginning of water stress period. Two curves showed different response to water stress (fig 2). Water stress began long before for the improved genotypes on May 24th, however, local genotypes were relatively insensitive to stress up to June 2nd. The reduction of relative yield continued to reach 55% and 70% for improved and local genotypes respectively. Concluding that local genotypes are more resistant to water stress than the improved genotypes is why local farmers prefer cultivating local genotypes despite their limited productive potential compared to the improved genotypes. This mixed farming-breeding system or traditional type of farming (Rouabhi *et al*, 2012) can play a paramount role to ensure the durability of these farms. (Milar & photakoun, 2008)

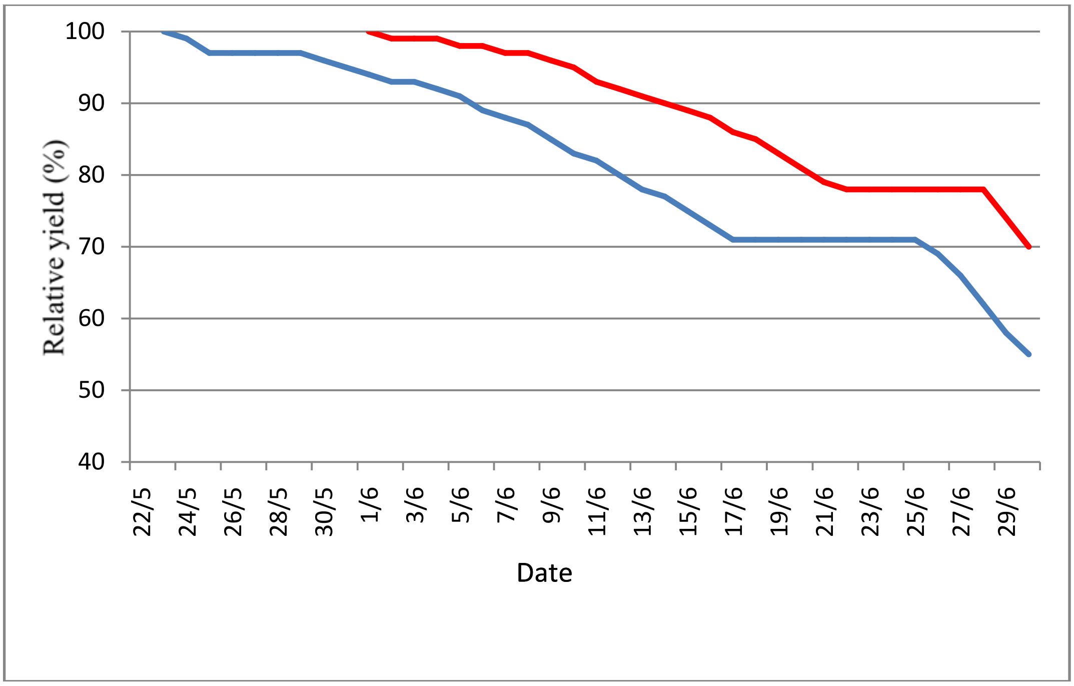

Fig. 3: Expected relative yield of local and improved genotypes under water stress.

4- Assessment of the potential yield:

An analysis of variance (ANOVA) was performed between local and improved genotypes grain yield, ANOVA showed a highly significant difference at 1% threshold, followed by LSD mean-comparison test. Results confirmed the superiority of improved genotypes with respect to their productive potential, improved genotypes formed a homogeneous group (A) with a mean of 67.46 q/ha, while the group of local genotypes (B & AB) of 49.75q/ha (Table 4).

Table 4: Grain yield homogenous groups.

genotypes	Rendement grain (q/ha)
Altar	(72,04) A
Dukem	(67,71) A
Kucuk	(61,96) A
Mexicali	(70,44) A
Sooty	(64,43) A
Waha	(68,22) A
Polonicum	(54,38) AB
Oued Zenati	(45,12) B

5- Assessment of water use efficiency:

Improved genotypes have registered relatively high yields of 67.46 q/ha, they have suffered low levels stress of 0.33, Water use efficiency (WUE) was defined as the ratio between grain yield and total growing season Evapotranspiration (Kang et al., 2002). Improved genotypes had WUE of 14.50 kg/mm/ha and local genotypes had WUE of 10.12 kg/mm/ha (Table 5). This implies that improved genotypes have a strategy to escape water stress settled during post anthesis period. The decline in theoretical yield (reduction in relative yield 55%) of improved genotypes was more marked because of the long period of stress which lasts 39 days, despite this long period, improved genotypes have registered high grain yield because of their genetic potential, however, local genotypes suffered more water stress of 0.60 caused by the combination of heat and water scarcity during the beginning of summer season. As mentioned by (Blum 2005) yield under water-limited conditions can be determined by the genetic factors controlling yield potential, and/or drought resistance, and/or WUE

Table 5: Effect of Water stress on grain yield and Water use efficiency.

Genotype	Grain yield (q/ha)	Water use efficiency (kg/ha/mm)	Expected relative yield	Average Water stress	Maximum Water stress	Water stress period (day)
Local	49.75	10.12	70%	0.37	0.60	30
Improved	67.46	14.50	55%	0.33	0.54	39

Conclusion:

Water stress and uneven distribution of rainfall are the main constraints yields of rainfed crops in semi-arid climate. Indeed, this season had a very poor distribution of rainfall, where the majority was in March and April, following by a long drought period, where the crop requires water to complete its cycle. In relation to global climate change; this goal involves improving local varieties representing the type of semi-arid climate with productive skills and drought tolerance. The use of *BUDGET* crop mode has enhanced yield component analysis by providing the calculation parameters for plant, soil and climate such as water stress, Evapotranspiration, and root zone depletion, these data may be used for screening of suitable genotypes for the local climate. In the light of the model simulation results, we can say that the simulations of the evolution of soil moisture were approved reliability. Values of the water stress did confirm that the action of terminal stress on local genotypes is more significant than improved genotypes. To allow good operating model at the local level, should be multiplied applications simulations on the scale of time and space, to provide a historical database containing all the varietal information, crop conditions, the results of simulations and models validation.

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