Original article

Plant traits and phenotypic variability effect on the phytomass production of *Stipagrostis ciliata* (Desf.) De Winter

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A B S T R A C T

A process of continuous degradation of plant communities, due mainly to long-term overgrazing has been revealed by most ecological studies in North African arid climate. Notably, this degradation appeared across the depletion of perennial grass species exhibiting low density in the majority of range ecosystems. This study aimed to examine the phenology and the aboveground phytomass production of *Stipagrostis ciliata* (Desf.) De Winter accessions, a perennial grass, growing under the same environment but coming from different climates of Tunisia. Additionally, the extent of genetic variation in phenological parameters, root and shoot phytomass productivity and the correlations among these parameters were also analyzed. Significant differences in all morphological parameters of *S. ciliata* accessions were revealed by ANOVA test and were corroborated with significant and positive correlation indicated by Pearson's correlation analysis. Plant diameter, biovolume, root biomass with protective sleeve and spike number exhibited significant differences and high distinctiveness between *S. ciliata* accessions. Tukey's HDS tests indicated the presence of three groups of accessions. Principal component analysis (PCA) applied on a table with eight observations and 13 variables, and dispersion of *S. ciliata* accessions on the first two axes of PCA confirmed the presence of three groups of accessions. Trait variability in the field for the five accessions is more likely to be the result of phenotypic plasticity rather than of genetic differentiation between accessions. Overall, the characterization of *S. ciliata* accessions exhibited significant differences in terms of morphological and biomass productivity.

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1. Introduction

Unequivocal evidence of ongoing climate change characterized by important modifications in rainfall patterns and increase in temperature globally has been provided recently (IPCC, 2013). Climate change is bound to impact the structure and functioning of terrestrial ecosystems (Penuelas et al., 2013) especially under arid and semi-arid bioclimate. Climate change-induced promotion in important changes in the spatial extent and distribution of vegetation communities is also known worldwide (Gang et al., 2013). Ear-

lier, global change has also been reported to alter biodiversity worldwide at an unpredicted rate, with important consequences for the functioning of natural ecosystems (Chapin et al., 2000). Additionally, aridity was also predicted to increase worldwide during the actual century (Feng and Fu, 2013).

Dry rangelands world-wide are prone to concurrent high levels of human activities and high climatic variability (Reynolds et al., 2007). Consequently, a decrease and change in vegetation cover, structure and diversity with a subsequent loss of the systems productivity is possible (Le Houérou, 2005). In arid zone, major biodiversity loss can also be the result of a low specific richness and rapid succession from one vegetation type to another that in turn is significantly influenced by the bioclimatic aridity. (Parmesan, 2006; Walther, 2010; Li et al., 2013; Juan et al., 2017). In addition, these areas are also sensitive to human activities such as grazing and deforestation which were found to promote dry land desertification (Hudak, 1999; Knapp et al., 2007). In particular, overgrazing reduces the abundance of palatable species and increases that of unpalatable one, promotes strong changes in the dry regions rangelands and eventually results in degradation of natural vegeta-

List of abbreviations

MA	Matmata	SpN	tuft spike number
GA	Gabes	SeN	tuft seed number
BH	Bou Hedma	LeaN	tuft leaf number
BK	Bir Ali ben khalifa	AgB	Aboveground biomass
SF	Sfax	RootB1	Root Biomass with protective sleeves
PL	tuft length	RootB2	Root Biomass
PD	tuft diameter	PtW	Plant Total Weight
BV	tuft biovolume	HI	Harvest Index
TN	tiller number	RUE	Rain Use efficiency

tion and ecosystem functioning and services (Chaieb et al., 1996; Hendricks et al., 2005; Gaitan et al., 2014; Eldridge and Delgado-Baquerizo, 2016).

In the degraded rangelands, the improvement of food productivity and quality requires the ecological restoration of these ecosystems through human intervention (Aronson and Le Floc'h, 2000). The natural plant communities' regeneration is very slow under arid and dry conditions and is necessary to reintroduce artificially the extinct perennials grasses. The use of autochthonies species with high palatability may be needed to restore these rangelands (Marshall et al., 2012). Under Mediterranean bioclimate, the paleo-tropical species C_4 pathway are very useful for maintaining a functional complementarity with C_3 perennial *grass* (Chaieb et al., 1996). In fact, these species are useful in restoration of North African degraded arid ecosystems. As well many other grasses species of the arid zones (*Stipa lagascae* R & D, *Tricholaena teneriffae Cenchrus ciliaris* L., *Digitaria nodosa* Parl., *Stipagrostis ciliata* Desf. and the Saharan species (*Panicum turgidum* Forssk., *Danthonia forskaholii* (Vahl) were impeded by other chamaephytes such *Astragalus armatus, Hamada scoparia, Artemisia campestris* having a very low palatability value. Maintaining a good nutritional quality and high biological productivity of the rangeland and reducing wind erosion requires rehabilitation of degraded ecosystems. The restoration of vegetation in these conditions with use of native species requires preliminary studies of their behavior, in particular their phytomass production morphological variability and responses to drought. Knowledge of their growth and their vegetative and reproductive performance will reflect on the possibility of their integration into the ecological restoration process in the concerned regions. The characteristic of the functioning of Mediterranean ecosystems, especially those of arid and dry zones, is the diversity of plant behavior in the relation to the environmental factors variability (Le Houérou, 2002). This is expressed through both the morphological diversity and biomass production. The study of this variability is the key for understanding how plant communities respond to climate change and to environmental factors especially rainfall and temperature and their influence on potential evapotranspiration (Mseddi et al., 2002; Mbatha and Ward, 2006). In arid zones of Tunisia, several authors (Mseddi et al., 2004) underlined the strong correlation between annual precipitation and plant growth such as start of the growth and aerial phytomass produced by perennial grass with a large grassland and rangeland biogeographical distribution. However, information is lacking in literature regarding the potential occurrence of (a) variability between the different accessions of the same xerophytes species; (b) correlations between all the surveyed parameters; and (c) the influence of bioclimate in particular precipitations on the growth and adaptation of C_4 species such as *Stipagrostis ciliata* (Desf.) De Winter in arid areas.

In fact, Violle et al. (2007) showed that functional traits are indicators of plant performance responses to environmental factors. Important efforts have been devoted to documenting the relationships between functional traits and environmental factors, leading to the identification of several axes of variation, of which a major one is related to the resource-use strategy and leaf life span of species (Floret et al., 1990; Reich et al., 2003). Given above, this study aimed to investigate the productive capacity and phenologicals traits of *Stipagrostis ciliata* (Desf.) De Winter, one of the most promising C_4 grass species in the world and that belongs to *Poaceae* family and occurs in arid Mediterranean and tropical habitats, and in North African rangeland ecosystems (Roger, 2003; Hosney et al., 2009; Daur, 2012). Herein, efforts were made to examine major plant functional traits including morphological characteristics (plant height, and leaf number), biomasses (aboveground and belowground), and growth indices (root-to-shoot ratio, spike number) of five Tunisian S. ciliata accessions coming from different arid bioclimate and growing under the similar environment.

2. Material and methods

2.1. Plant material

Stipagrostis ciliata (Desf.) De Winter has wide ecological and geographical amplitude in North Africa and grows under a variety of environmental conditions. Its distribution covers the desert regions of the South and the North Sahara (Milton and Dean, 2000; Fish, 2003; Hosney et al., 2009). *S. ciliata* exhibited a low density and low recruitment in Tunisia ecosystems. This perennial densely tufted grass exhibits leaves basally concentrated and forming a rounded hummock with the flowering culms emergent, and possess unique biological and ecological characteristics (Table 1). Its height rarely exceeds 1.0 m that makes it easy to be accessed by the animal. The occurrence of *S. ciliata* indicates that rangelands are in well ecological equilibrium. The leaves are somewhat linear and significantly glabrous (De Winter, 1965). *S. ciliata* prefers the gypsum and sandy soils with low concentrations of N and P.

2.2. Morphological and surveyed productivity parameters

A total of five accessions of *S. ciliata* were chosen in this study (Table 2). The accession from national protected Park of Bou Hedma (34°39′N and 09°48′E) located in the Governorate of Sidi Bouzid (Central Southern Tunisia) was designated as BH. Accession coming from Matmata (in the south of country) and accession coming from Gabès (south east of Tunisia) were designated as MA and GA respectively. Accession SF and BK were respectively from regions of Sfax and Bir Ali ben Khalifa. Origin sites showed significant heterogeneity in soil and bioclimate (Table 2). The experiment was performed at an experimental site in Sfax. The climate is arid Mediterranean with mild winters. Pots were filled with 10 kg of sandy soil. One day before sowing, pots were watered at field capacity. Five seeds were sown in each pot. During the first year 2011/2012, irrigation was applied whenever needed in order

Table 1
Biological and ecological characteristic of *Stipagrostis ciliata* (Desf.) De Winter.

Item	Botanical and ecological characteristic	Reference
Family	*Poaceae*	
Life cycle	Perennial	
Biological type	Hemicryptophyte	Raunkiaer (1937)
Photosynthetic pathway	C4	Sage and Monson (1999)
Optimal temperature of germination	25 °C	Mnif et al. (2018)
Soil type preferendum	Gypsohalocline	Leistner, (1967)
Biogeographical repartition	- North Africa - South Africa, Namibia, Zimbabwe - Western Saudi Arabia - Iran, Pakistan, Afghanistan	Hosney et al. (2009) Margaretha et al. (2008)
Ecological interest	- Indicators species for good pastoral area - Protects soil from erosion - Tolerates aridness and wind erosion - Tolerates the gypso-alcaline soils	Roger (2003)Le Houérou (2002)Daur (2012)
Appetability	-Is one of best forages grasses	Hosny et al. (2009)
Caryotype	x = 11	Hillu (2007)
Weight of 1000 seeds	2.9 gr	Ahmed et al. (2012)
Reproduction	Facultatively cleistogamous	Hamasha et al., 2012

Table 3
Surveyed morphological and productivity parameters of studied *Stipagrostis ciliata* accessions.

Number	Parameters	Code of parameters	Unit of measure
1	Tuft length	PL	cm
2	Tuft diameter	PD	cm
3	Tuft biovolume	BV	cm^3
4	Tiller number	TN	Numb.
5	Tuft spike number	SpN	Numb.
6	Tuft seed number	SeN	Numb.
7	Tuft leaf number	LeaN	Numb.
8	Aboveground biomass	AgB	gr DM
9	Root biomass with protective sleeves	RootB1	gr DM
10	Root biomass	RootB2	gr DM
11	Plant total weight	PtW	gr DM
12	Harvest index	HI	%
13	Rain use efficiency	RUE	gr DM m^{-2} mm^{-1}

to guarantee the establishment of the plant material. After the establishment year, *Stipagrostis* plants were cut for the first time. From then (during the second year 2013/2014), data were collected relating to the growth cycle. The experimental design was a complete randomized block design with 5 replications for each accession. Rainfall data were recorded at the Institute's weather station located near the experimental site.

Measurements of morphological and phenological functional traits were made across growth season (Table 3). A second growth period began in spring 2014 when temperatures were favorable for growth and finished when soil water became limiting by the end of spring. All parameters were measured on the same period to allow comparisons among five adult invidious for each studied accession.

2.3. Vegetative and reproductive growth phases

During the experiment, several functional traits were measured on each studied accession. The vegetative phase started at the end of growth period and ended on the date of first spike appearance. During the tillering phase, tuft length and diameter, tuft biovolume, tiller number, and tuft leaf number were measured. On the other hand, the reproductive growth period began with the appearance of the first spike. It stopped in the beginning of summer when the tuft dried up (second growth period). Parameters observed included tuft spike number and tuft seed number. At the end of the cycle of growth, all the tufts from each accession (5 invidious) were cut at a 2-cm stubble height and dry matter of the aerial part of the plant was weighed. Dry mass weight of the root system of each tuft and its ratio to aerial dry mass were also determined. Biomass was dried for 24 h at 105 °C and weighed. All biomass data are expressed as g tuft^{-1}. Harvest index was determined by dividing the fresh aboveground biomass by total plant weight and the obtained value was expressed in percentage. The ratio of root and shoot was determined by dividing the root dry mass by the shoot dry mass. To calculate the Rain Use Efficiency (RUE) of *Stipagrostis ciliata* accessions, precipitation was recorded regularly during study period. RUE was estimated by dividing the above ground by the total of annual rainfall saved in the study site of each accession. RUE was expressed in g dry mass (DM) m^{-2} mm^{-1}.

2.4. Data analysis

The significance of differences among the parameters observed was analyzed by ANOVA and then the averages were compared by Tukey's HDS test. Pearson's correlation coefficient was computed and data were analyzed. Correlation analysis was used to estimate

Table 2
Geographical location of the studied sites of *Stipagrostis ciliata* accessions and their ecological characteristics for the study year 2013/2014.

Name of site of observation	Geographical characteristics				Bioclimatic characteristics			
	Accession code	GPS coordinates	Bioclimate type (Emberger 1954)		Annual Precipitation (mm)	M (°C)	M (°C)	Soil type
		Latitude	Longitude					
Bou Hedma	BH	34° 27′ N	09° 39′ E	Wet Arid	220	36.2	3.8	Sandy soil
Matmata	MA	33° 53 ′ N	10° 01′ E	Wet Arid	177	35.4	4.2	Loam soil
Sfax	SF	34° 73′ N	10° 63′ E	Wet Arid	210	31.5	6.5	Sandy soil
Gabes	GA	34° 10′ N	09° 59′ E	Dry Arid	165	33	6.1	Sandy soil
Bir Ali ben Khalifa	BK	34° 45′ N	10°13′ E	Dry Arid	191	35	7	Sandy soil

the relationship between the studied variables. The values of the probability lower than 0.05 were regarded as statistically significant. Principal component analysis (PCA) was performed to get a synthetic appraisal of the whole data set. All analyses were done using the SPSS version 22 statistical package.

3. Results

3.1. 1. Above ground biomass and root biomass production

Comparative studies on aboveground biomass of *S. ciliata* accessions showed significant differences in dry matter accumulation (F = 2.986; P = 0.053) (Fig. 1). Range of variation and principal results of the ANOVA are in Table 4. Dry matter produced by tufts varied from 260.15 ± 20.35 g to 93.7 ± 12.3 g with a mean of 167 g. This variability emphasizes the importance of variability in intraspecific phytomass production in this species. Additionally, this variability also proved the importance of the precipitation effect on the production of phytomass. In fact accessions BH and SF growing respectively in Bou Hedma and Sfax those received the high quantity of rainfall (respectively 220 and 210 mm) were the most productive. The MA and GA accessions growing under more arid sites kept the same range of phytomass productivity. In contrast, the root biomass was insignificant between accessions (F = 1.417; P = 0.276) (Table 4). There was significant difference in root shoot ratio between accessions which averaged 0.24 (Fig. 2). Root biomass with protected sleeves showed significant differences between accessions (F = 6.526; P = 0.003), this proved the differences in adaptation to arid bioclimate of studied *S. ciliata* accessions (Table 4). On the other hand, accessions differed considerably in root weight with protected sleeves.

3.2. Levels of phenotypic variation

The five studied accessions exhibited a bimodal growing cycle in the autumn 2013 and spring season 2014. In autumn, growth was much less important. The high growth of new leaves during spring depends strongly on soil water stock accumulated through the winter season. The variation of mean spikes number per tuft was shown in Fig. 3. In fact, the reproductive intensity appeared to be variable according to accessions. However, the mean number of spikes produced by each individual plant of BH, SF, BK, MA and GA accessions and during the spring growth cycle was only a mean of 54.5; 31.75; 25.81; 9.0 and 8.0 spike tuft^{-1} respectively. The results of the F-tests, next to the mean values of plant diameter, biovolume and spike number showed very significant difference

Table 4
Variation of root dry matter between the different studied accessions.

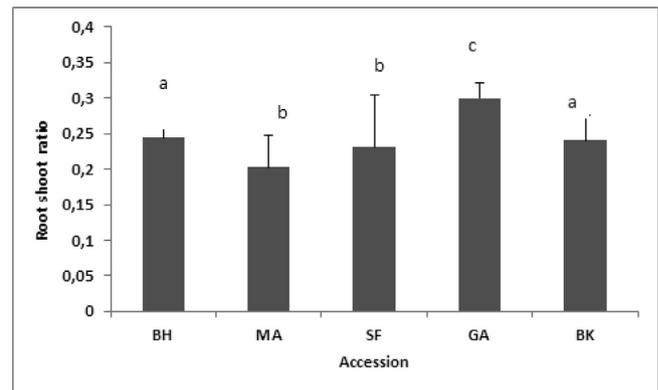| Accession	Root dry matter with protective sleeves	Root dry matter
BH	63.55 ± 12	16 ± 3.25
MA	25.32 ± 8	11.75 ± 3
SF	44.44 ± 8.23	13.87 ± 2.5
GA	28.12 ± 5.23	13.25 ± 2.87
BK	40.36 ± 10	13.71 ± 3
f	6.527	1.417
p	0.003	0.276

Fig. 2. Root /shoot dry matter ratio for *Stipagrostis ciliata* during the growth cycle.
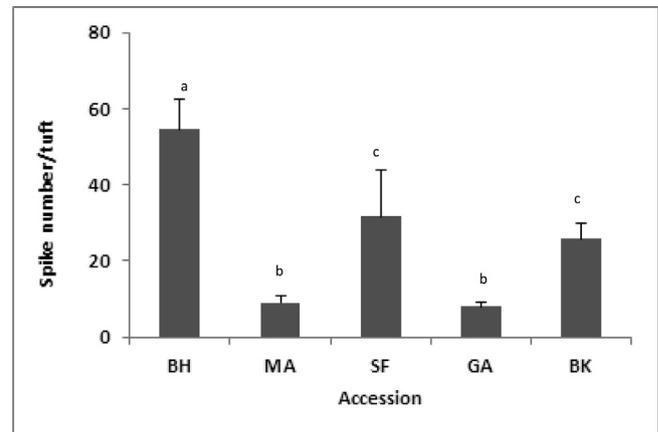

Fig. 3. Variation of spike number/tuft between *Stipagrostis ciliata* accessions. Bars represent the mean ± SE (n = 8). Bars with Different letters are significantly different within accessions (Tukey's HDS test P < 0.05).
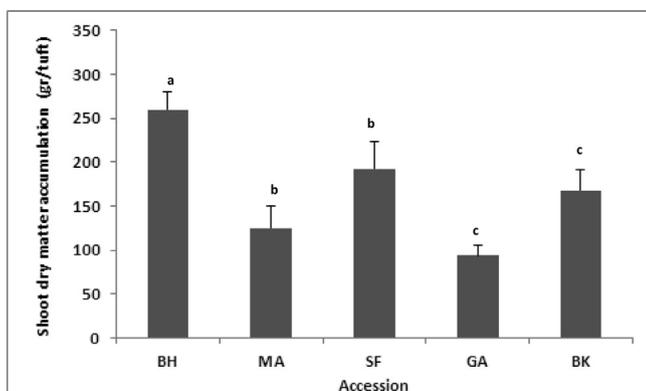
between *S. ciliata* accessions (Table 5; Fig. 3). Significance tests for the differences of means indicated a high distinctiveness of accessions. In fact, Tukey's HDS test showed that accession BH was one group for the plant biovolume, diameter, spike number and leaf number (Fig. 4).

3.3. Pearson's correlations among productivity and phenology

The results of pair wise correlations among functional traits are shown in Table 6. Significant positive correlation among majority of the evaluated morphological characters was observed. Correlations between root biomass (RootB1), spike number (SpN) and stem number (TN) were absent. Specifically, BV and TN were uncorrelated with five studied parameters (SeN, AgB, RootB1, PtW and HI). The reproductive effort appeared to be variable according to *S. ciliata* accessions. However, the mean number of

Fig. 1. Shoot dry matter accumulation per each tuft for five *Stipagrostis ciliata* accessions. Bars with Different letters are significantly different within accessions (Tukey's HDS test P < 0.05).

Table 5
Summary of the variance analysis for morphological and productivity parameters.

	N°	Parameter	*F*	*P*
1	Tuft length	4.311	0.016	
2	Tuft diameter	8.044	0.001	
3	Tuft biovolume	6.679	0.003	
4	Tiller number	4.842	0.010	
5	Tuft spike number	6.526	0.003	
6	Tuft seed number	2.209	0.117	
7	Tuft leaf number	2.986	0.053	
8	Aboveground biomass	3.350	0.038	
9	Root biomass with protective sleeve	6.527	0.003	
10	Root biomass	1.417	0.276	
11	Plant total weight	3.553	0.031	
12	Harvest index	2.515	0.085	
13	RUE	4.123	0.001	

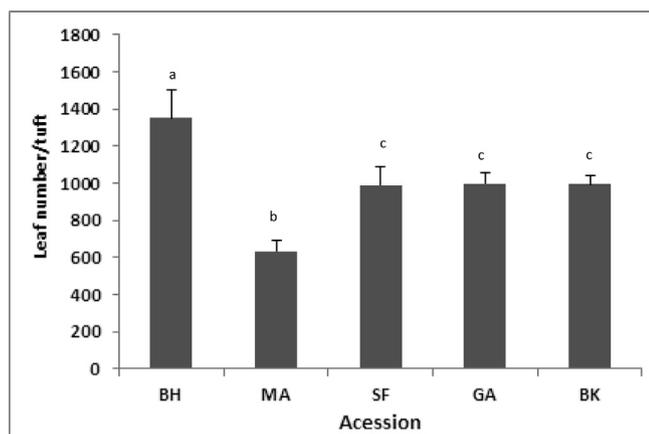n = 8, significant differences p = 0.05.

Fig. 4. Variation of mean leaf number/tuft between *Stipagrostis ciliata* accessions. Bars represent the mean ± SE (n = 8). Bars with Different letters are significantly different within accessions (Tukey's HDS test $P < 0.05$).

spikes produced by BH accession was 54.5 ± 12. The differences among SpN were significantly and highly correlated with PL, PD, BV and TN parameters. A negative correlation (r^2 = −0.055) was found between number of leaves per plant (LeN) and the root biomass (Table 6).

3.4. Principal component analysis

Principal component analysis (PCA), presented in Table 7 included 8 observations and 13 variables namely PL, PD, BV, TN, SpN, SeN, AgB, RootB1, RootB2, PtW, LeaN, HI and RUE. PCA of the morphological and phytomass productivity characters showed two principal components accounting for approximately 74% of total variance value revaluated contributions of 18.93% and 55.07% for PC1 and PC2 respectively. On the first plane of this PCA, made by axes 1 and 2 (Fig. 5), SpN is located at the positive extremity of axis 1 (0.923). The parameters PL, PD, BV, TN and LeaN were located at the positive extremity of the axis 1. PCA reflected the results of ANOVA analysis, indicating that almost all morphological characters varied significantly between *S. ciliata* accessions.

Plotting the accessions on the first two axes as well as on the first and third factor graphically demonstrated that accessions of *S. ciliata* coming from different bioclimatic area covered the facto-

Table 7
Correlation co-efficient between the first three principal components and the aboveground phytomass and morphological characters.

Character	PC1	PC2	PC3
Cumulative contribution	55.08%	74%	82.7%
PL	0.791	−0.278	−0.012
PD	0.811	−0.204	−0.162
BV	0.872	−0.275	−0.209
TN	0.786	−0.494	−0.105
SpN	0.923	−0.023	−0.025
SeN	0.584	0.391	0.052
AgB	0.784	0.461	0.360
RtB1	0.707	0.667	−0.039
RtB2	0.669	0.250	−0.496
PtW	0.787	0.509	0.293
LeN	0.637	−0.661	−0.035
HI	0.363	−0.479	0.743
RUE	0.587	0.499	0.421

Table 6
Pearson's correlation coefficients of morphological characteristics.

	PL	PD	BV	TN	SpN	SeN	AgB	RootB1	RootB2	PtW	LeaN	HI	RUE
PL	1												
PD	0.790**	1											
BV	0.768**	0.903**	1										
TN	0.764**	0.722**	0.864**	1									
SpN	0.803**	0.778**	0.871**	0.790**	1								
SeN	0.491*	0.290	0.345	0.409	0.585*	1							
AgB	0.456*	0.444*	0.416	0.340	0.562*	0.499*	1						
RootB1	0.456*	0.496*	0.395	0.274	0.535*	0.531*	0.844**	1					
RootB2	0.466*	0.475*	0.463*	0.448*	0.533*	0.382	0.480*	0.622**	1				
PtW	0.466*	0.464*	0.422	0.336	0.570**	0.516*	0.995**	0.892**	0.517*	1			
LeaN	0.606**	0.569**	0.760**	0.838**	0.557*	0.146	0.080	−0.055	0.141	0.058	1		
HI	0.457*	0.400	0.410	0.390	0.380	0.105	0.449	0.006	−0.018	0.380	0.450*	1	
RUE	0.406	0.443	0.439	0.328	0.582	0.509	0979	0.808	0.464	0.968	0.150	0.355	1

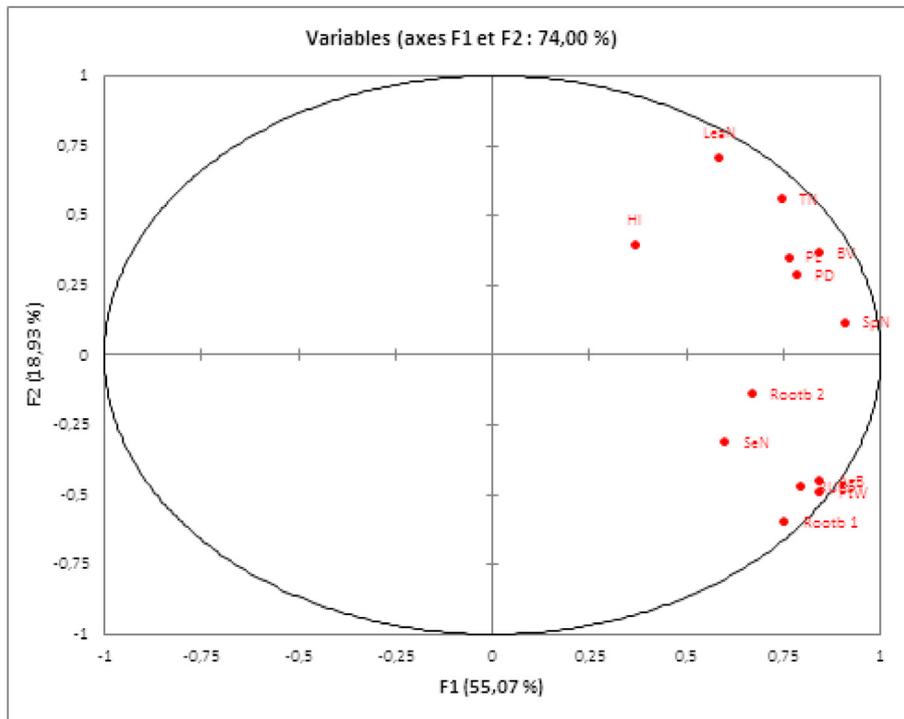* and **, significance at p = 0.05 and p = 0.01, respectively.

Fig. 5. Dispersion of observed variables in the first two axes of the principal component analyses.
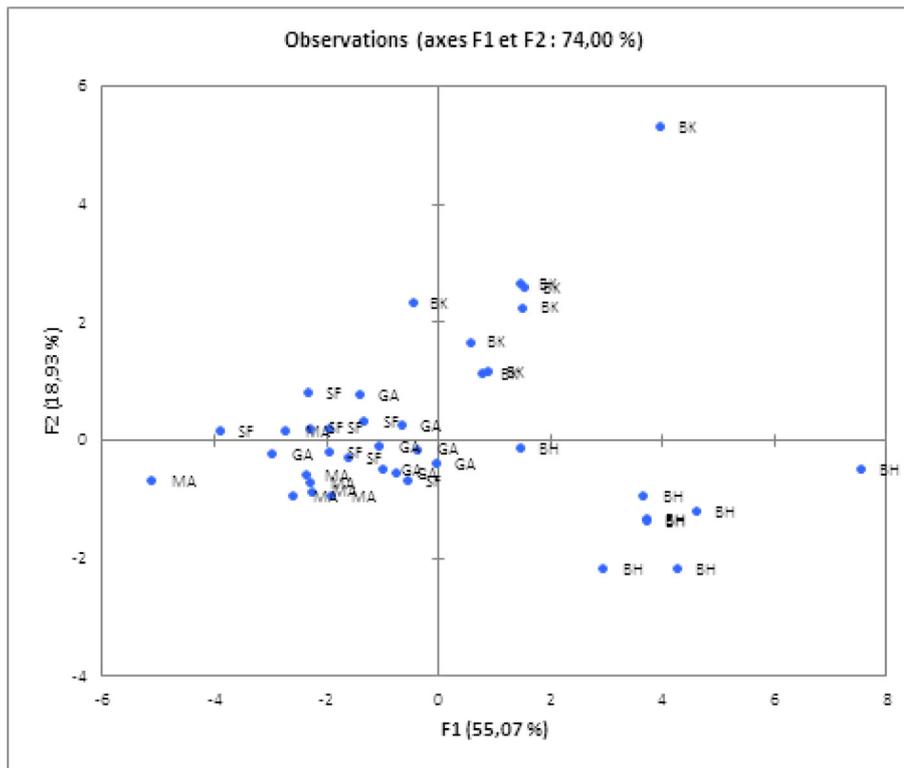

Fig. 6. Dispersion of *Stipagrostis ciliata* accessions on the first two axes of principal component analyses.

rial space unequally. Dispersion of accessions on the first two axes of principal component analysis confirmed the presence of three groups of accessions (Fig. 6). However, accession BK coming from Bir Ali ben Khalifa was located in the positive extremity of axis 1 and axis 2. It was characterized by a great mean spikes number

(SpN = 54.5 ± 5.26) and leaf number. Accessions MA, SF and GA were located in the negative extremity of the two axes. Harvest index was located at the positive extremity of axis 1 and 2. The highest harvest index was recorded in accession BK; whereas, the least was recorded for accession BH.

S. ciliata morphologic diversity and phytomass production were estimated by using multi-variant analyses of several morphological characters. In analysis into main components, the aggregation of 13 values equaled to data's total variance and a main component's value represented the contribution of component to total variance. Twelve values obtained from the components 1, 2 and 3 explained respectively 55.07%, 18.93% and 9.1% overall 82.7% of the variables total variance (Fig. 6). The coefficient of Eigen vectors in the first component shows that PL, PD, BV, TN, SpN, AgB, RootB1 and PtW had the greatest contribution to the first component. In the second component, RootB1 had higher Eigen vector coefficients compared to other parameters. In the third component, HI had the highest significance in explaining this component (Table 7).

4. Discussion

4.1. Aboveground phytomass production and rain use efficiency (RUE)

The biomass yield of ecosystems is dependent on the water availability and the ability of the species to convert energy into material that is economically useful. If any one of these factors becomes limited, the dry matter yield will decline. The yield of perennial grass becomes limited during drought season through the reduced soil water availability (Jeddi and Chaieb, 2010). *S. ciliata* is considered as an excellent pastoral species for arid zones and it is highly valued for the production and palatable forage. The variability in biomass production was proved by this study. In fact, BH accession could be preferred for the forage breeders because of its high morphological correlation with traits linked to productivity such as above ground phytomass. In this study, dry matter production can be considered as a good indicator of productivity variation among accessions. These could be useful for selection criteria of the most suitable accessions of buffel grass to restore the degraded Tunisians ecosystem (Kharrat-Souissi et al., 2011).

In arid zones characterized by high water deficits over long periods of the year, the root system of plants can be considered as the main moderator of competition between species, as well as their adaptation to drought. In terms of root distribution, the roots of perennial grass rarely exceeded a depth of 80 cm, most frequently explored moistened soil (Chaieb et al., 1996). The high density of the roots and their weight in the upper soil horizon can be due to the fact that, when subjected to high evaporative demand, this soil layer is often moistened by rain and the roots tend to locate there. The study of the root system of perennial grasses suggests that the high concentration of roots in the upper layer of the soil ensures the production of the species. The roots located at 0.5–0.8 m depth would have to ensure, in addition to the production under favorable water conditions, the survival of the species in period of water stress, since in depth, the soil is not completely desiccated. An important feature of the grass root system has been the development of mucilage around the roots which facilitates water absorption and maintains root growth in low soil moisture (Lijima et al., 2003; Mnif et al., 2005). The present study reported the variation in root shoot ratio between 0.2 and 0.4. These results are in agreement with the results of some studies carried out in other arid zones (Chaieb et al., 1992; Dhief et al., 2011; Gamoun, 2016). Root biomass with protected sleeves showed significant differences between accessions. This result proved the differences in adaptation to arid bioclimate of studied *S. ciliata* accessions. Thus, in the Tunisian arid zone, a shoot root ratio may vary with site and climatic conditions. However, root shoot ratio of *S. ciliata* accessions coming from different habitat varied significantly.

It is recognized that in arid and desert areas, crop production is clearly related to the soil water availability. In fact, the productivity of an ecosystem is revealed through its effectiveness with regard to the water availability. RUE equals to the slope of the relationship between annual rainfall and aboveground phytomass production (Le Houérou, 1984). In dry land conditions and elsewhere, it serves as an excellent indicator of soil fertility and, hence of ecosystem productivity. This study found substantial differences in RUE of *S. ciliata* accessions, where BH accession was the most efficient (1.12 g DM m^{-2} mm^1). GA accession growing in Gabès was the least with 0.57 g DM m^{-2} mm^1. For a given ecosystem, RUE was reported as a good indicator of the capacity of valorization of the rainwater by vegetation, mainly under arid and desert bioclimates (Le Houérou, 1984). For the same plant communities, the biomass production may be highly variable, from one environment to the other, in relation to the variability of soil, climate and the management practice (Maestre and Reynolds, 2007). In an excellent synthesis about the valorization of the rainwater for arid plant production, Le Houérou (1980) reported the RUE values in the range of 1.0 to 6.0 g DM m^{-2} mm^1 in arid and semiarid natural vegetation. However, RUE may be substantially lower in degraded ecosystems or considerably higher in arid conditions or under good management. In this context, it was reported earlier that combination with changes in the total amount of rainfall have the potential to affect the ecological processes such as survival, phenology and growth of plants, the composition and diversity of ecological communities (Knapp et al., 2002), and above- and below-ground productivity (Heisler-White et al., 2008).

4.2. Morphological variability between accessions

Under arid bioclimate, the life cycle of *S. ciliata*, when the soil water availability during early autumn is adequate and when the temperature is favorable for the growth of C$_4$ plant photosynthesis. Usually, under the Mediterranean arid conditions, the C$_4$ perennial grasses is thought to be highly drought tolerant and have a bimodal growth season autumn and spring (Mnif et al., 2005; Mnif and Chaieb, 2006). Gibbs-Russel et al. (1990) showed that *S. ciliata* flowering and sets seed in two periods of the year (November and March). Usually *Stipagrostis* species are pollinated by wind and are facultative cleistogamous. This is not the case of the North African ecotype where *Stipagrostis* genus is a good perennial pastoral species and considered as a hemicryptophyte (Raunkiaer, 1937).

Along an experimental productivity gradient, all accessions expressed a large amount of intraspecific variation for functional traits. In the present study, important variations observed for different morphological and productive parameters and confirmed by the ANOVA test, showed a strong phenological and morphological variability among *S. ciliata* accessions coming from different Tunisian regions and bioclimate. This complies with results of studies in arid ecosystems, on morphological variability of other perennial grasses. In the south of Tunisia, Mseddi et al. (2002) and Mnif el al. (2005) have reported the presence of large variability between *Cenchrus ciliaris* accessions, C$_4$ species, a candidate species for the restoration of degraded ecosystems in North Africa. Using the dispersion of *S. ciliata* accessions on the first two axes of PCA (Fig. 6), the accessions could be grouped into three groups. On the PCA dispersion, tested variables were divided into two distinct groups: the first group of variables (PL, PD, BV, TN, LeN) correlated with positive extremity of axis 1 and negative extremity of axis 2 which described seed numbers, root and shoot dry weight. Whereas, the second group of variables was correlated with negative extremity of axis 1 and positive extremity of axis 2 and characterized the vegetative growth of plants (PtW, AgB, RootB1, RootB2, SeN, RUE). The PCA confirmed that characters such as plant length, spike number, tuft diameter and biovolume are important to distinguish between accessions. Major groups constituted by

cluster analysis were also detected in the PCA. The most important morphological parameters were those with high loading on the first and second components. These observations agree with the classification criteria that are mainly based on extreme morphological characters such as plant height, plant biovolume, number of tiller etc. The correlation reveled by Pearson correlation matrix in this study, confirms the existence of these three groups (Table 5). Spike production, tuft height and diameter can also be adaptive traits to climatic variations and grazing pressure. Positive correlation between both phenological and reproductive parameters showed that *S. ciliata* invested its reserves for spike reproduction as well as for growth during the growth cycle. The mostly positive correlations between parameters attested that at the period of growth *S. ciliata* grows both in height and diameter.

This study further differentiated *S. ciliata* accessions studied and the 13 studied parameters which were significantly different. It also identified three highly diverse accessions providing opportunities for optimizing parental source in future breeding program. These results also showed that the phenotypic variations of *S. ciliata* accessions growing under the same climatic and edaphic conditions can reflect probably some intra-genetic variations within this species. However, the application of molecular approaches may prove this intraspecific variability between accessions and growing in different bioclimate. In this context, Bauert et al. (1998) showed that genetic diversity is considered to be important for adaptations to environmental change, and consequently for the long-term survival of plant populations. Additionally, genetic diversity is assumed to increase with abiotic and biotic heterogeneity and in stressful environments (Wang et al., 2006). Hamasha et al. (2012) reported that genetic variation of Jordanian *Stipa* populations, as estimated by AFLPs, is influenced not only by the predominant random processes but also by bioclimatic conditions. This variability could be valued for ecological restoration of degraded ecosystems under arid bioclimate, where environmental conditions are unfavorable for plants establishment and growth. In this context, the most developed individuals could provide seeds for artificial reseeding of degraded ecosystems, when perennial grass presented a low density in their ecosystems (Le Floch, 2001).

5. Conclusion

S. ciliata is an excellent pasture grass for dry areas in Tunisia and can survive in a range of harsh environmental conditions. This study confirmed the occurrence of a high intraspecific variability among *S. ciliata* accessions mainly as a result of intraspecific differences along climate gradient between accessions in key morphological parameters.

The variations observed in the present study also do not decline the value of mean traits as strategy indicators, but rather suggest that trait variation could be equally informative about plant response to environment However, other parameters such as vegetative and reproductive growth, dry matter and habitat type, can also be considered in futures studies on the subject and investigations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Ahmed, K.O., Muhammad, A.Z., Sohir, T.H., Nagwa, R.A.H., 2012. Fruit morphology of annual grasses from Egypt. Asian J. Plant Sci. 11 (6), 268–284.

Aronson, J., Le Floc'h, E., 2000. Editorial: restoration of natural capital: pros and problems. Restor. Ecol. 8, 214–216.

Bauert, M., Kaelin, R., Baltisberger, M., Edwards, P.J., 1998. No genetic variation within isolated relict populations of *Saxifraga cernua* in the Alps using RAPD markers. Mol. Ecol. 7, 1519–1527.

Chaieb, M., Floret, C., Le Floch, E., Pontanier, R., 1992. Life history strategies and water resource allocation in five pasture species of the Tunisian arid zone. Arid Soil Res. Rehabil. 6, 1–10.

Chaieb, M., Henchi, B., Boukhris, M., 1996. Impact of clipping on root systems of 3 grass species in Tunisia. J. Range Manag. 49, 336–339.

Chapin, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C., Díaz, S., 2000. Consequences of changing biodiversity. Nature 405, 234–242. https://doi.org/10.1038/35012241.

Daur, I., 2012. Plant flora in the rangeland of western Saudi Arabia. Pak. J. Bot. 44, 223–269.

De winter, B., 1965. The South African *Stipeae* and *Aristideae* (*Gramineae*). An anatomical, cytological and taxonomy study. Bothalia 8 (3), 199–404.

Dhief, A., Abdellaoui, R., Tarhouni, M., Ouled Belgacem, A., Ashi Smiti, S., Neffati, M., 2011. Root and aboveground growth of rhizotron-grown seedlings of three Tunisian desert *Calligonum* species under water deficit. Can. J. Soil Sci. ISSN 91 (1), 15–27.

Eldridge, D.J., Delgado-Baquerizo, M., 2016. Continental-scale impacts of livestock grazing on ecosystem supporting and regulating services. Land Degrad. Dev. https://doi.org/10.1002/ldr.2668.

Feng, S., Fu, Q., 2013. Expansion of global dry lands under a warming climate. Atmos. Chem. Phys. 13, 10081–10094.

Floret, C., Galan, M.J., Le Floc'h, E., Orshan, G., Romane, F., 1990. Growth forms and phenomorphology traits along an environmental gradient: tools for studying vegetation. J. Veg. Sci. 1, 71–80.

Fish, L., 2003. Poaceae. In: Germishuizen, G., Meyer, N.L., (Eds.), Plants of Southern Africa: An Annotated Checklist. Strelitzia, pp. 1190–1191.

Gamoun, M., 2016. Rain use efficiency, primary production and rainfall relationships in desert rangelands of Tunisia. Land Degrad. Dev. 27, 738–747.

Hamasha, H.R., Schmidt-lebuhn, A.N., Durka, W., Schleuning, M., Hensen, I., 2012. Bioclimatic regions influence genetic structure of four Jordanian *Stipa* species. Plant Biol., 1–10

Hosny, A., Mosallam, A., Morsy, A., Youssef, M., Ahmed, A., 2009. Structure of the common plant population along Alamain-WadiEl-Natrun Desert Roat. Aust. J. Basic Appl. Sci. 3 (1), 177–193.

Hillu, K.W., 2007. Skewed distribution of species number in grass genera: is it a taxonomic artifact. In: Hodkinson, T.R., Parnell, J.A.N. (Eds.), Reconstructing the Tree of Life: Taxonomy and Systematic of Species Rich Taxa. CRC Press, Taylor & Francis, New York, USA, pp. 165–176.

Hendricks, H.H., Bond, W.J., Midgley, J.J., Novellie, P.A., 2005. Plant species richness and composition a long livestock grazing intensity gradients in a Namaqualand (South Africa) protected area. Plant Ecol. 176, 19–33.

Heisler-White, J.L., Knapp, A.K., Kelly, E.F., 2008. Increasing precipitation event size increases aboveground net primary productivity in a semi-arid grassland. Oecologia 158 (1), 129–140.

Hudak, A.T., 1999. Rangeland mismanagement in South Africa: failure to apply ecological knowledge. Hum. Ecol. 27, 55–78.

IPCC. (Intergov. Panel Clim. Change) (2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed. TF Stocker, D Qin, G-K Plattner, M Tignor, S.K. Allen, et al. Cambridge, UK: Cambridge Univ. PressKarem A, Ksantini M, Schoenenberger A, and Waibel T. (1993. Contribution à la regeneration de la vegetation dans les parcs nationaux en Tunisie aride, Tunis. Ministère de l'Agriculture. p. 21.

Kharrat-Souissi, A., Baumel, A., Mseddi, K., Torre, F., Chaieb, M., 2011. Polymorphism of *Cenchrus ciliaris* L. a perennial grass of arid zones African. J. Ecol. 49 (2), 209–220.

Knapp, A.K., Fay, P.A., Blair, J.M., Collin, S.L., Smith, M.D., Carlisle, J.D., Harper, C.W., Danner, B.T., Lett, M., McCarron, J.K., 2002. Rainfall variability, carbon cycling, and plant species diversity in a mesic grassland. Science 298, 2202–2205.

Knapp, A.K., Briggs, J.M., Collins, S.L., Archer, S.R., Bret-Harte, M.S., Ewers, B.E., Peters, D.P., Young, D.R., Shaver, G.R., Pendall, E., Cleary, M.B., 2007. Shrub encroachment in North American grasslands: shifts in growth form dominance rapidly alters control of ecosystem carbon inputs. Glob. Change Biol. 14, 615–623.

Gibbs-Russel, G.E., Watson, L., Koekemoer, M., Smook, L., Barker, N.P., Anderson, M., Dallwitz, M.J., 1990. Grasses of Southern Africa. Memoirs of the Botanical Survey of South Africa 58, 437.

Gaitán, J., Bran, D., Oliva, G., Maestre, F., Aguiar, M.R., Jobbágy, E.G., Buono, G., Ferrante, D., Nakamatsu, V., Ciari, G., Salomone, J., Massara, V., 2014. Vegetation structure is as important as climate for explaining ecosystem function across Patagonian rangelands. J. Ecol. 102, 1419–1428.

Gang, C., Zhou, W., Li, J., Chen, Y., Mu, S., Ren, J., Chen, J., Groisman, P.Y., 2013. Assessing the Spatiotemporal Variation in Distribution, Extent and NPP of Terrestrial Ecosystems in Response to Climate Change from 1911 to 2000. https://doi.org/10.1371/journal.pone.0080394.

Jeddi, K., Chaieb, M., 2010. Changes in soil properties and vegetation following livestock grazing exclusion in degraded arid environments of South Tunisia. Flora 205, 184–189.

Juan, J., Gaitán Donaldo, E.B., Gabriel, E.O., Martín, R.A., Gustavo, G.B., Daniela, F., Viviana, N., Georgina, C., Jorge, M.S., Virginia, M., Guillermo, G.M., Fernando, M. T., 2017. Aridity and overgrazing have convergent effects on ecosystems structure and functioning in Patagonian rangelands. Land Degrad. Dev., 1–9

Le Houérou, H.N., 1980. The rangelands of the Sahel. J. Range Manag. 33, 41–46.

Le Houérou, H.N., 1984. Rain use efficiency: A unifying concept in arid land ecology. J. Arid Environ. 7, 213–247.

Le Houérou, H.N., 2002. Man-made deserts: desertification processes and threats. Arid Land Res. Manag. 16, 1–36.

Le Houérou, H.N., 2005. Atlas of climatic diagrams for the isoclimatic Mediterranean Zones Montpellier: Copymania.

Le Floc'h, E., 2001. Biodiversité et gestion en zones arides et semi-arides méditerranéennes du Nord de l'Afrique. Bocconea 13, 223–237.

Leistner, O.A., 1967. The plant ecology of South Kalahari. Memoirs Botanical Surv. South Africa 38, 1–172.

Lijima, M., Sako, Y., Rao, T.P., 2003. A new approach for the quantification of root-cap mucilage exudation in the soil. Plant Soil 255, 399–407.

Li, X.Y., Zhang, S.Y., Peng, H.Y., Hu Ma, Y.J., 2013. Soil water and temperature dynamics in shrub-encroached grasslands and climatic implications: results from Inner Mongolia steppe ecosystem of north China. Agr. Forest Meteorol. 171, 20–30.

Maestre, F.T., Reynolds, J.F., 2007. Biomass responses to elevated CO_2, soil heterogeneity and diversity: an experimental assessment with grassland assemblages. Oecologia 151, 512–520.

Margaretha, W., Van Rooyen Jacobus du, P., Bothm Hendrik, M., van den Berg, 2008. Landscapes in the Kalahari Gemsbok National Park, South Africa. African Protected Area Conservation Sci. 50 (1), 99–122.

Marshall, V.M., Lewis, M.M., Ostendorf, B., 2012. Buffel grass (*Cenchrus ciliaris*) as an invader and threat to biodiversity in arid environments. A Review J. Arid Environ. 78, 1–12.

Mbatha, K.R., Ward, D., 2006. Determining spatial and temporal variability in quantity and quality of vegetation for estimating the predictable sustainable stocking rate in semi-arid savanna. Afr. J. Range For. Sci. 23, 131–145.

Milton, S.J., Dean, W.R.J., 2000. Disturbance, drought and dynamics of desert dune grassland, South Africa. Plant Ecol. 150, 37–51.

Mseddi, K., Visser, M., Neffati, M., Rehaul, D., Chaieb, M., 2002. Seed and spike traits from remnant populations of *Cenchrus ciliaris* L., in South Tunisia: high distinctiveness, no ecotypes. J. Arid Environ. 50, 309–324.

Mseddi, K., Mnif, L., Chaieb, M., Neffati, M., Roux, M., 2004. Aboveground phytomass productivity and morphological variability of Tunisian accessions of *Cenchrus ciliaris* L. Afr. J. Range For. Sci. 21 (1), 49–55.

Mnif, L., Ouled Belgacem, A., Cortina, J., Chaieb, M., 2005. A comparative analysis of the establishment of *Cenchrus ciliaris* provenances in arid zone of Tunisia. Arid Land Res. Manag. 19 (4), 341–351.

Mnif, L., Chaieb, M., 2006. Comparative phenology and growth of four *Cenchrus ciliaris* L. accessions established under arid bioclimate in Tunisia. Afr. J. Ecol. 44 (4), 531.

Mnif, L., Anjum, N.A., Chaieb, M., 2018. Assessment of temperature and water limitation effects on the germination of *Stipagrostis ciliata* seeds collected from Bou Hedma, Central South Tunisia. J. Arid. Land. 10 (2), 304–315.

Raunkiaer, C., 1937. Plant Life Forms. Clarendron, Oxford, p. 104.

Reynolds, J.F., Smith, D.M., Lambin, E.F., Turner, B.L., Mortimore, M., Batterbury, S.P., Downing, T.E., Dowlatabadi, H., Fernández, R.J., Herrick, J.E., Huber-Sannwald, E., Jiang, H., Leemans, R., Lynam, T., Maestre, F.T., Ayarza, M., Walker, B., 2007. Global desertification: building a science for dry land development. Science 316, 847–851.

Roger, P.E., 2003. Stipagrostis ciliata (Desf.) De Winter var. capensis (Trin.& Rupr.) De Winter. The Consilience Engine Ecoport RSA Country Programme. p. 2.

Reich, P.B., Wright, I.J., Craines, J.M., Oleksyn, J., Westoby, M., Walters, M.B., 2003. The evolution of plant functional variation: traits, spectra and strategies. Int. J. Plant Sci. 164, S143–S164.

Parmesan, C., 2006. Ecological and evolutionary responses to recent climate change. Annu. Rev. Ecol. Evol. Syst. 37, 637–669.

Peñuelas, J., Sardans, J., Estiarte, M., Ogaya, R., Carnicer, J., Coll, M., Barbeta, A., Rivas-Ubach, A., Llusià Garbulsky, M., Filella, I., Jump, A.S., 2013. Evidence of current impact of climate change on life: a walk from genes to the biosphere. Glob. Change Biol. 19 (8), 2303–2338.

Sage, R.F., Monson, R.K., 1999. The Taxonomic Distribution of C_4 Photosynthesis. In: Sage, R.F., Monson, R.K. (Eds.), C4 plant biology. San Diego, CA, USA: Academic Press, pp. 551–584.

Violle, C., Navas, M.L., Vile, D., et al., 2007. Let the concept of trait be functional. Oikos 116, 882–892.

Walther, G.R., 2010. Community and ecosystem responses to recent climate change. Philos. Trans. Royal Soc. B. 365, 2019–2024.

Wang, J.L., Zhao, N.X., Gai, Y.B., Lin, F., Ruan, W.B., Chen, L., 2006. RAPD analysis of genetic diversity and population genetic structure of *Stipa krylovii* roshev, In Inner Mongolia steppe. Russ. J. Genet. 42, 468–475.