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Development of height inequality in *Zea mays* L. and *Panicum capillare* L. when grown under stress conditions.

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Abstract

Panicum capillare L. (Poaceae) is an annual, dominant weed of cotton, maize and other economically important crops of Lasbela District of Balochistan province of Pakistan. The effect of P. capillare competition on size inequality of well-fertilized and irrigated crop of maize (Zea mays L.) was studied at a local farm of Uthal area of Lasbela District. The traditional method (broadcasting) of seeding of Z. mays was implemented during the present study. Monoculture and mixture plots (1 x 1 m^{-2}*) of P. capillare and Z. mays were established with four replicates. The plant heights of weed and crop were measured after 30 days of seeding and recorded every ten day interval till the final harvest (70 days after seeding).*

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The interspecific competition between Z. mays and P. capillare significantly affects the aboveground biomass of Z. mays ($P < 0.01$). On the other hand, there was no significant difference ($P < 0.3$) in aboveground biomass of P. capillare. The distributions of P. capillare plant height were positively skewed (L-shaped) when grown in competition with Z. mays. However, P. capillare plant height was negatively skewed (J-shaped) in monoculture stands. On the other hand Z. mays plant height showed positive skewed (L-shaped) in monoculture and negative skewed (J-shaped) in mixture with P. capillare stands. The higher Lorenz curve and Gini coefficient values of plant height were observed in mixed stands of Z. mays and P. capillare compared with monospecific stands. These results also illustrate that both weed and crop showed weak development of hierarchies in aboveground heights in both monospecific and mixed stands.

Key words: *Zea mays* L., *Panicum capillare* L., Lasbela, size inequality, Lorenz curve, Gini coefficient.

Introduction

Competition between individual plants for a limiting resource such as light is usually reflected in the development of size asymmetry in the population, where larger individuals often obtain a greater share of available resources and subsequently suppress the growth of their smaller neighbors (Weiner and Thomas 1986, Weiner 1988, Weiner 1990, Schwinning and Weiner 1998). The term asymmetry competition is synonymous with several other terms such as one-sided competition (Firbank and Watkinson 1987), dominance and suppression (Schwinning and Weiner 1998), resource pre-emption and snowball competition (Weiner and Thomas 1986). Competition for light differs from that for other resources such as nutrients in that competition for nutrients intensifies soon after germination whereas competition for light begins only when plants are large enough to shade one another (Weiner 1988).

Size inequality in plant populations can readily be calculated using various models and computer software (Sen 1973, Weiner and Solberg 1984, Weiner 1986, Ellison 1987, Dixon 1993, Shumway and Koide 1995). Size asymmetry is a common feature in most plant populations, where taller and/or larger individuals have a competitive advantage over shorter and/or smaller individuals (DiTommaso and Watson 1997). Size asymmetry in plant populations may be determined by age differences, genetic differences, environmental heterogeneity, maternal effects such as seed size, the effect of herbivores, parasites or pathogen, competition, and the interaction among these factors (Weiner 1985, Weiner and Thomas 1986, DiTommaso and Watson 1997).

Plant density plays an important role in determining size hierarchy in a species (Weiner and Thomas 1986, Miller and Weiner 1989). Weiner and Thomas (1986) listed 16 size-asymmetric competition cases, where 14 out of 16 became asymmetric with increasing density. It was observed that a population of a species grown at higher densities showed greater size asymmetry than a population of a species grown at lower densities over the same period (Weiner and Thomas 1986). For example, *Salicornia europaea* grown at low mono-specific densities were taller, heavier had greater stem diameters and branched more profusely than for plants grown in pure stand at higher densities (Ellison 1987). The height inequality between low and high densities of *S. europaea* was, however, the same in mono- specific stands, because *S. europaea* did not self thin (Ellison 1987). Ellison (1987) concluded that most annual plants exhibit lower height hierarchy variation in mono - specific stands until density approaches 10,000 plants m^{-2}. Working on a *Trifolium incarnatum-Lolium multiflorum* competition system, Weiner (1985) reported that *L. multiflorum* in mixture with *T. incarnatum* showed a greater competitive ability resulting in lower inequality of dry biomass compared with *L. multiflorum* grown in monospecific stands. However, *T. incarnatum* in mixture exhibited a greater dry biomass inequality than in pure stand.

Panicum capillare L. originally a native species in North America, is an annual weed with erect or prostrate stems which reached the height of 20–100 cm and occasionally exhibit lateral branches at the base (Clements *et al*. 2004). It was reported that *P. capillare* has been introduced in different temperate zones throughout the world as a fodder grass, including Argentina, Chile, Europe, Asia New Zealand and Australia however it escaped and became a serious weed in these countries (Holm *et al.* 1979). *P. capillare* is a major weed of maize (*Zea mays*) and soybeans (Clements *et al*. 2004). Under favourable field conditions *P. capillare* can produce 56,400 seeds per plant that remain viable in the soil for long periods in a variety of environments (Clements *et al*. 2004). It was suggested that *P. capillare* apparently a poor competitor compared with *Amaranthus retroflexus* and *Chenopodium album* (Kroh and Stephenson 1980). Similarly, it was observed that *P. capillare* was more susceptible to inter-specific competition compared with intra-specific competition (Kroh and Stephenson 1980).

Lasbela District is a part of the Balochistan Province of Pakistan lies between 65^0 12′1″ to 67^0 25′39″ East longitudes and $24^0$53′2″ to $26^0$39′20″ North latitudes on southern coast. The district has central alluvial lowland drained by the Porali and Kud Rivers suitable for cultivation. Climate of the area is typical dry and hot. The prevailing arid to semi-arid environmental conditions with annual rainfall less than 200 mm for a long period resulting a greater evapo-transpiration than precipitation and provides an ideal situation for drought tolerance cereal crops. However local farmers of this area along with cereal crops are also used to grow new varieties of fodder and cash crops. Cultivation of *Zea mays* along with cotton is a recent phenomenon in this region. A recent survey of weeds of Lasbela District conducted by Baloch *et al.* (2013) reported that *P. capillare* is the most common weed of cotton fields along with *Cyperus rotundus*.

To our knowledge, it is the first time the effects of light competition on height hierarchy of *P. capillare* and *Z. mays* when grown alone (monoculture) and in competition were studied in the Lasbela

District.

The specific objectives of this research were to determine the effect of intraspecific and interspecific competition on height hierarchies of *Z. mays* and *P. capillare*. It is hypothesized that the effect of competition on size inequality of *Z. mays* and *P. capillare* is more pronounced when grown in mixed plots compared with mono-specific stands.

Materials and Methods

Field experiments were conducted at Shahjahan Lodhi Madina Agriculture farm at Uthal, Lasbela District, Balochistan, Pakistan, during the months of July-September 2013. The experimental site was ploughed and cultivated with maize (*Zea mays* L.) in the summer season of 2013. Fertilizer (N-P-K) was applied at a rate of 250 Kg ha^{-1}. Maize seeds were broadcasted in the field without any row spacing which is a common practice in this area. During trials, monospecific stands of *P. capillare*, *Z. mays* and mixture plots of *P. capillare* and *Z. mays* were established in 1m by 1 m plots arranged in randomized complete block design with four replicates. In monospecific plots of *Z. mays* and *P. capillare* all weed species were removed by hands except maize and *P. capillare*. Similarly in mixture plots maize and *P. capillare* were allowed to grow and rest of weeds were removed by hands. In each plot the heights of individual plants were measured from the soil surface to the pennant apex. Successive measures of heights of *Z. mays* and *P. capillare* were measured every ten days interval till the final harvest at 70 DAS (days after seeding). At harvest, height and cumulative aboveground biomass of *Z. mays* and *P. capillare* from 1 x 1 m plots were recorded.

The effect of weed/crop competition was determined by using the GLM procedure of SPSS programme (IBM 2011). The analysis of variance (ANOVA) procedure was modified in order to take into account the potential heterogeneity of variances and lack of independence over time of the temporal repeated measures of individual plants height (Dutilleul 1998).

The skewedness and kurtosis of the data were determined with SPSS (IBM 2011). Skewedness provides a measure of the degree of asymmetry in the frequency distribution (DiTommaso and Watson 1997). Positive and negative values of skewedness are expressed as L-shaped and J-shaped distributions, respectively. Zero skewedness suggests a symmetrical distribution (DiTommaso and Watson 1997). Kurtosis indicates the peakedness of the distribution (Nagashima *et al.* 1995) and positive or negative values of kurtosis suggest that the distribution is more peaked (leptokurtic) or bimodal (platykurtic) (Nagashima *et al.* 1995).

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The inequality among crop and weed plants in height and dry weight was assessed using the Lorenz curve and the Gini coefficient (Weiner and Solberg 1984). The Lorenz curve provides the detailed structure of size inequality and allows one to identify the regions where significant size differences occur between distributions. Using the Lorenz curve, individual plants (*Z. mays* and *P. capillare*) were ranked from the smallest to the largest with respect to the parameter measured. The cumulative fractions of individual plants (p) were plotted against the cumulative fraction of the dependent variable L (p) such as plant height (Mehran 1975, Weiner 1985, Shumway and Koide 1995). The Lorenz curve for p and L(p) range from $[p_o, L(p_o)]$, $[p_1, L(p_1)]$,…, $[p_k, L(p_k)]$, $[p_k+1=L(p_k+1)]$, with $p_o = L(p_o) = 0$ and $p_k+1 = L(p_k+1) = 1$. Specifically, the value of the Gini coefficient is equal to twice the area between L (p) and the 45^0 line equality (Mehran 1975).

The Gini coefficient has a minimum value of 0, when all of the individual *Z. mays* and *P. capillare* plants have the same height for example, while the maximum value 1.0 represent an infinite population in which all individuals, but one, have a value of 0 (Weiner and Solberg 1984). For n plants having a mean height of x, the Gini coefficient (G) is given by,

$$G = \frac{1}{2\bar{x}n(n-1)}\sum_{i=1}^{n}(2i-n-1)X_i$$

where, X_i are sizes sorted from smallest to largest $X_1 \leq X_2 \leq \ldots\ldots X_n$. (Dixon *et al*. 1987). The precision and confidence intervals for the Gini coefficient were calculated by using the bootstrapping method defined by Dixon *et al*. (1987) and Dixon (1993). The bootstrapping procedure provides error estimate and 95% confidence intervals (CI) for the Gini coefficients of Plant height (Weiner and Solberg 1984). The bootstrapping sequence was carried out using the SPSS system (IBM 2011).

Results

The aboveground biomass of *P. capillare* did not show any significant difference when grown in monoculture and in competition with *Z. mays* at final harvest (Figure 1 b). However the aboveground biomass of *Z. mays* was severely affected (P<0.01) when grown in mixture with *P. capillare* compared with when grown alone (Figure 1 a).

The height hierarchy among *P. capillare* plants was negatively skewed (J-shaped) in mono-specific stands and positively skewed (L-shaped) in competing populations with *Z. mays* (Figs. 3 a, b). On the other hand the height inequality among *Z. mays* plants was positively skewed (L-shaped) when grown in monospecific stands and negatively skewed (J-shaped) when grown in completion with *P. capillare* (Figs. 2 a, b). In general, there was no specific trend observed in *Z. mays*. The value of skewedness, kurtosis, and unbiased Gini coefficient for *Z. mays* and *P. capillare* plants height are shown in Table 1. Although inequality among individual plants of both species varied, but did not affect time-course of skewedness, kurtosis and unbiased Gini coefficient values. *Z. mays* developed strongly J-skewed and leptokurtic populations. *Z. mays* population did not show any specific trend and similarity in all height categories with no evidence of size inequality. *Z. mays* crop in monospecific and in mixture with *P. capillare* stands showed positive skewedness of plant height (highest values for lower and upper limits; 0.702-1.379 in monospecific and 0.677-2.225 in mixture population respectively, (Table 1)). A similar skewedness trend was observed in *P. capillare* when grown in monospecific and in mixture with *Z. mays* crop highest values for lower and upper limits; 0.53-1.493 in mono-specific and 0.799-2.579 in mixture population respectively, (Table 1)). Although highest skewedness was evident in mixture plots but bimodality in height which is according to Nagashima *et al*. (1995) a trait indicative of the coexistence of two canopy levels within the same population was not evident in *Z. mays* and *P. capillare* when grown in mono-specific population. The highest kurtosis was evident in *Z. mays* (-1.06 and 2.225 for lower and upper limits) and *P. capillare* (-1.49 and 7.404 for lower and upper limits) when grown in mixture plots (Table 1). The unbiased Gini coefficient values for *Z. mays* did not show any difference when grown in monospecific (0.131) and mixture (0.133) plots (Table 1). However in case of *P. capillare* the highest Gini coefficient (0.196) was observed among plants grown in competition with *Z. mays* (Table 1). The lower Gini value for *Z. mays* plant height resulted in a less concave area below the diagonal in the Lorenz curve (Figs. 4a and b). However for *P. capillare* plant height, the area below the diagonal was more concave when grown in competition with *Z. mays* (Fig. 5b).

The size hierarchy development in both *Z. mays* and *P. capillare* showed a linear trend, however temporal inequality in heights resulted in significant ($P < 0.0001$) impacts on final heights of these plants (Table 2).

Discussion

Interaction among individuals of same species and between different species resulted in height hierarchy development (Thomas and Bazzaz 1993). It was suggested that competition with neighbouring plants leads to population with L-shaped frequency distribution that resulted into few large and many small individuals (Vega and Sadras 2003).The height hierarchy among the neighboring plants is more prominent in a situation where plants compete for light, because changes take place in spectral composition of light when it penetrate into different strata of standing plants (Ballaré *et al*. 1994). To examine the effects of height hierarchies in *Z. mays* and *P. capillare*, belong to Poaceae, but differ in their ability to tolerate crowding, was studied. According to Fuksa *et al*. (2004) the weed infestation decreases the height of maize plants by 0.39 m in the check variant compared with the chemical one. The results of present study revealed that the general frequency distribution of *Z. mays* plant height was L-shaped when grown in monospecific stands and J-shaped when grown in competition with *P. capillare*. The results of present study are relatively varied with the findings of Vega and Sadras (2003) where they noticed normal or J-shaped frequency distributions of aerial parts of *Z. mays* when grown in monoculture. The results of present study indicated that interference among the neighboring plants in *Z. mays* when grown in monoculture were drove the processes of height inequality. The traditional method of seeding of *Z. mays* in Lasbela District mostly done by broadcasting seeds in well ploughed soil and normally no row spacing applied. Therefore the number of seedlings per unit area varied, that resulted into an uneven plant population density per unit area which resulted into strong height hierarchies. Temporal variations in plant height in *Z. mays* indicated that at early stages of growth displayed a normal or J-shaped frequency distribution, however in later stages it shifted into L-shaped frequency distribution when grown in mono-specific stands (Fig. 2(a)). These results were striking because the bimodality in plant height hierarchy over time is not common in *Z. mays*. According to Vega and Sadras (2003), when sunflower height compared with maize and soybean, only sunflower showed bimodality over time. It was suggested that bimodality can be a result of a situation when competing plants allocated more energy in lower canopy compared with upper parts (Nagashima *et al*. 1995). In *Chenopodium album* bimodality common at early stages of growth as compared with later growth stages where frequency distributions of aboveground biomass became more positively skewed (**Nagashima *et al.* 1995**). Similarly individuals with different growth rate and asymmetrical competition for resources also enhanced the bimodality in plant height (**Ford 1975).**

The lower unbiased Gini values (G′) were observed in both *Z. mays* and *P. capillare* plants grown in mono-specific stands and in mixture plots. The inequality in architectural structure and height of both plants can be the reason of lower Gini value. However number of taller plants was higher in mono-specific plots compared with mixture that resulted into significant differences in aboveground biomass. Because asymmetry in height among the individuals *Z. mays* plants enhanced the efficacy of taller individuals to intercepted more light for photosynthesis compared with shorter ones that resulted into inequality in biomass (Anten and Hirose 2001).

In present study the collective aboveground biomass of both *Z. mays* and *P. capillare* was taken and therefore the inequality based on aboveground biomass among the individual plants of both species was not observed. Weiner (1985) reported that G′ values of aboveground biomass in *Lolium multiflorum* were positively correlated with plant density. At higher densities, *L. multiflorum* aboveground biomass frequency distributions were positively skewed and had greater G′ values as compared with plants grown at lower densities (Weiner 1985). DiTommaso and Watson (1997) reported that G′ values at three *A. theophrasti* seeding densities (125, 250 and 350 seeds m^{-2}) were relatively low when plants were grown in monospecific stands. However, size inequalities were significantly greater (i.e. higher G′ values) when *A. theophrasti* plants were inoculated with *Colletotrichum coccodes* and harvested at 2, 5 and 8 weeks after application of the fungal pathogen.

The results of present study indicate that *Z. mays* interspecific competition had a substantial effect on *P. capillare* size hierarchy development possibly because of direct interference in light interception. Because of its architectural structure which is mostly prostrate and occupied available open space and resources there was no significant difference in aboveground biomass observed in *P. capillare* in both mono-specific and mixture stands. However, under favourable conditions the height hierarchy in mixture stands gradually changed as *Z. mays* canopy occupied more open spaces available for *P. capillare* and unable the light spectrum to penetrate on surface of soil. Those *P. capillare* individuals those were able to outpace *Z. mays* canopy closure grew to relatively large sizes, but many of these plants were not able to break through the canopy, thus increasing the size inequality in mixture plots. Results of the present study revealed that the frequency distribution of *P. capillare* plant height was L-shaped at early stages of growth, however, in turned into L-shaped in later stages in nonspecific stands (Fig. 3a). On the other hand, in mixture plots *P. capillare* showed a drastically increased in size (J-shaped) in later stages of growth (Fig. 3b). Architectural differences between *P. capillare* and *Z. mays* may have also been responsible for the increased size in *P. capillare* in later stages of growth compared with *P. capillare* grown in pure stands. Walker *et al.* (1981) reported that soybean seeded at a narrow row spacing of 25.4 cm significantly reduced *Cassia obtusifolia* growth compared with plants of this species grown in monospecific stands.

Architectural complexity in *Z. mays* is pronounced and even under a favorable condition and in the absence of neighbouring plants, *Z. mays* displays a large amount of branching that included basal tillering and ear shoots (Moulina *et al.* 1999). The branching pattern in *Z. mays* provides an optimal arrangement of leaves in space such that plants are more efficient at intercepting sunlight and at developing sufficient leaf tissue to over inter-plant space rapidly. In contrast, *P. capillare* plants grown in the presence of *Z. mays* produced only a main stem with later prostrate blades, while in monospecific stands *P. capillare* plants also produced later prostrate branches in addition to the weak main stem which produced terminal floral parts. These structural differences exaggerated *P. capillare* size inequality in mixture plots that resulted into a lower aboveground biomass.

The findings of this work demonstrated that *Z. mays* interspecific competition was largely responsible for the size hierarchy differences observed in *P. capillare* which also affected the size hierarchy particularly aboveground biomass in *Z. mays* populations. The greater asymmetric size and biomass inequalities observed in plants which grown in mixture stands compared with mono-specific stands. It is likely that under the stress conditions examined in this study, few large individuals will contribute relatively more biomass and reproductive output to the population than suppressed individuals. These differences will be less apparent in mono-specific stands where plant architecture and competitive abilities will be relatively equivalent. The findings in this research also suggest that *Z. mays* can effectively suppress P. capillare growth and reproduction under subtropical dry desert environment of Lasbela District, Balochistan, Pakistan. To our knowledge, it is first time that different trends of height hierarchies' models used for the analysis of weed-crop competition in Pakistan; therefore this area is open for further research in different economically important crops of Pakistan.

References:

Anten, N.P.R. and Hirose T. 2001. Limitations on photosynthesis of competing individuals in stands and the consequences for canopy structure. Oecologia. 129: 186-196.

Ballaré, C.L., Scopel, A.L., Jordan, E.T. and Vlestra R.D. 1994. Signaling among neighboring plants and the development of size inequalities in plant populations. Proceedings of the National Academy of Sciences of the USA. 91: 10094-10098.

Baloch, A.H., Ahmed, I., Ahmed, S., and Buzdar, M.A. 2013. Ecological aspects of weeds in cotton fields of District Lasbela, Balochistan, Pakistan. *In press*.

Clements, D. R., DiTommaso, A., Darbyshire, S. J., Cavers, P. B. and Sartonov, A. D. 2004. The biology of Canadian weeds. 127. *Panicum capillare* L. Can. J. Plant Sci. 84: 327–341.

DiTommaso, A. and A.K. Watson. 1997. Effect of the fungal pathogen, *Colletotrichum coccodes*, on *Abutilon theophrasti* height hierarchy development. J. Appl. Ecol. 34: 518-529.

Dixon, P.M. 1993. The bootstrap and the jackknife: Describing the precision of ecological indices. In Design and Analysis of Ecological Experiments (S.M. Scheiner & J. Gurevitch eds) pp. 290-318. Chapman & Hall, London UK.

Dixon, P.M., J. Weiner, T. Mitchell-Olds and R. Woodley. 1987. Bootstrapping the Gini coefficient of inequality. Ecology 68: 1548-1551.

Dutilleul, P. 1998. Incorporating scale in study design and data analysis. In Scale Issues in Ecology. (Peterson D.L. and Parker, V.T. Eds.) New York, Columbia University Press NY. pp. 387-425.

Ellison, A.M. 1987. Density-dependent dynamics of *Salicornia europaea* monocultures. Ecology 63: 737-741.

Firbank, L.G. and A.R. Watkinson. 1987. On the analysis of competition at the level of the individual plant. Oecologia 71: 308-317.

Ford, E.D. 1975. Competition and stand structure in some even-aged plant monocultures. Journal of Ecology 63: 311-333.

Fuska, P., Hakl, J., Kocourková, and Veselá, M. 2004. Influence of weed infestation on morphological parameters of maize (*Zea mays* L.) Plant and Environ. 50: 371-378.

Holm, L., Pancho, J. V., Herberger, J. P. and Plucknett, D. L. 1979. A geographical atlas of World weeds. John Wiley & Sons, New York, NY. 391 pp.

Kroh, G. C. and Stephenson, S. N. 1980. Effects of diversity and pattern on relative yields of four Michigan first year fallow field plant species. Oecologia 45: 366–371.

Mehran, F. 1975. Bound on the Gini index based on observed points of the Lorenz curve. J. Am. Stat. Associat. 70: 64-66.

Miller, T.E. and J. Weiner 1989. Local density variation may mimic effects of asymmetric competition on plant size variability. Ecology 70: 1188-1191.

Moulina, B., C. Loup, M. Chartier, J.M. Allirand and C. Edelin. 1999. Dynamics of architectural development of isolated plant of maize (*Zea mays* L.), in a non-limiting environment: the branching potential of modern maize. Annals of Botany, 84: 645-656.

Nagashima, H., I. Terashims, and S. Katoch. 1995. Effect of plant density on frequency distribution of plant height in *Chenopodium album* stand: analysis based on continuous monitoring of height-growth of individual plants. Ann. Bot. 75: 173-180.

Schwinning, S. and J. Weiner. 1998. Mechanisms determing the degree of size asymmetry in competition among plants. Oecologia 113: 447-455.

Sen, A. 1973. On Economic Inequality. Clarendon, Oxford, UK. 260 p.

Shumway, D.L. and R.T. Koide. 1995. Size and reproductive inequality in mycorrhizal and nonmyccorrhizal population of *Abutilon theophrasti*. J. Ecol. 83: 613-620.

Thomas, S.C. and F.A. Bazzaz. 1993. The genetic component in plant size hierarchies: norms of reaction to density in a *Polygonum* species. Ecological Monographs 63: 231-249.

Walker, R.H., T. Whitwell, J.R. Harris, D.L. Thourlow and J.A. McGuire. 1981. Sicklepod control in soybean with herbicide, row spacing and planting dates. Alabama Agric. Exp. Stn. Highlights of Agric. Res. 28: 18.

Weiner, J. 1985. Size hierarchies in experimental population of annual plants. Ecology 66: 743-752.

Weiner, J. 1988. Variation in the performance of individuals in plant populations. *In* Plant population ecology (A.J., Davy, M.J. Hutchings and A.R. Watkinson eds.) pp 59-81. Blackwell, Oxford.

Weiner, J. 1990. Asymmetric competition in plant population. TREE 5: 360-364.

Weiner, J. and O.T. Solberg, 1984. The meaning and measurement of size hierarchies in plant populations. Oecologia 61: 334-336.

Weiner, J. and S.C. Thomas. 1986. Size variability and competition in plant monocultures. Oikos 47: 211-222.

Vega, C.R.C. and V.O. Sadras. 2003. Size-development growth and the development of inequality in Maize, Sunflower and Soybean. Annals of Botany 91: 795-805.

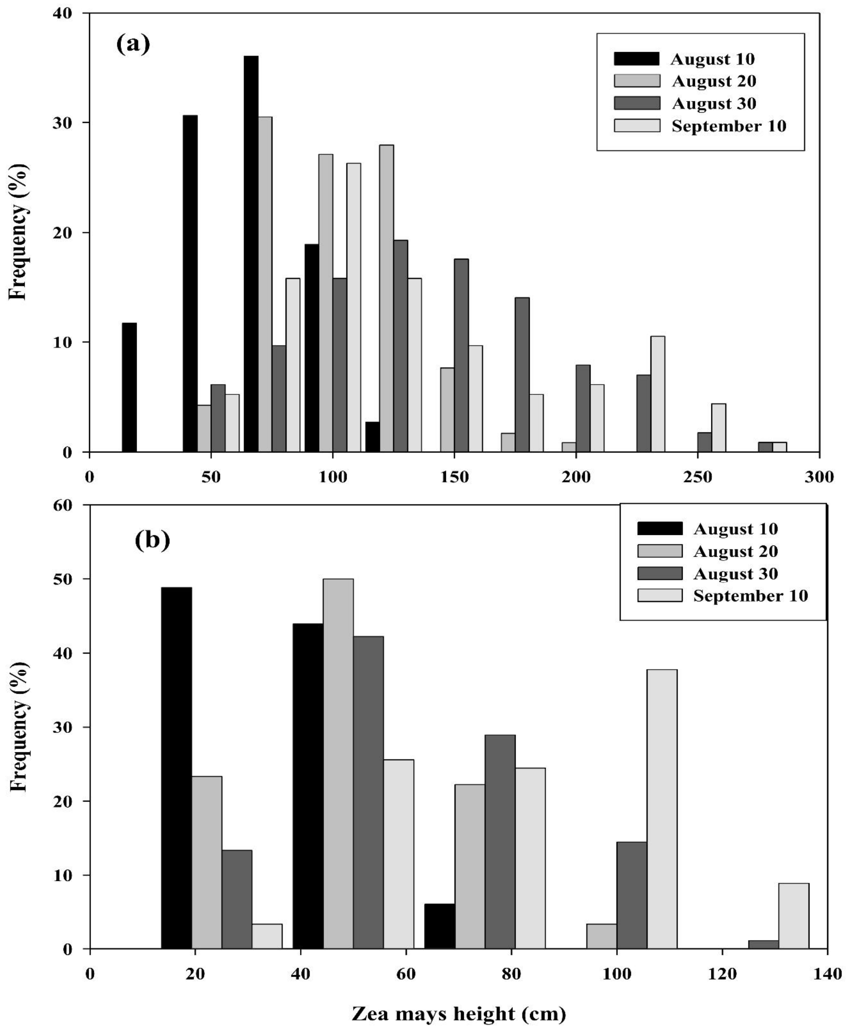

Figure. 2. (a) Frequency distribution of *Zea mays* height hierarchy development when grown in monospecific stands (b) and in competition with *P. capillare* at different stages.

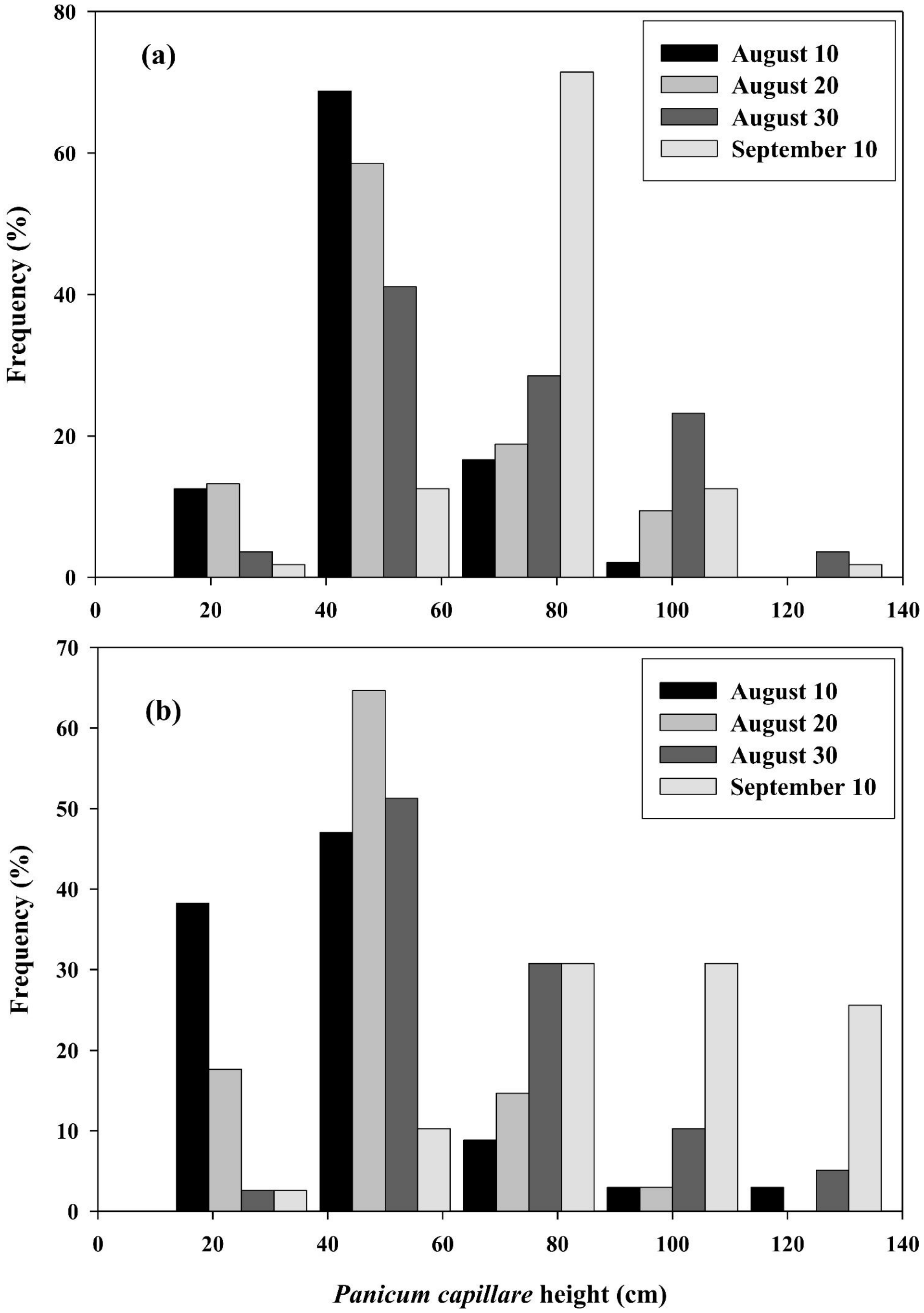

Figure 3. (a) Frequency distributions of *Panicum capillare* height hierarchy development when grown in monospecific and (b) in competition with *Zea mays* at different visits.

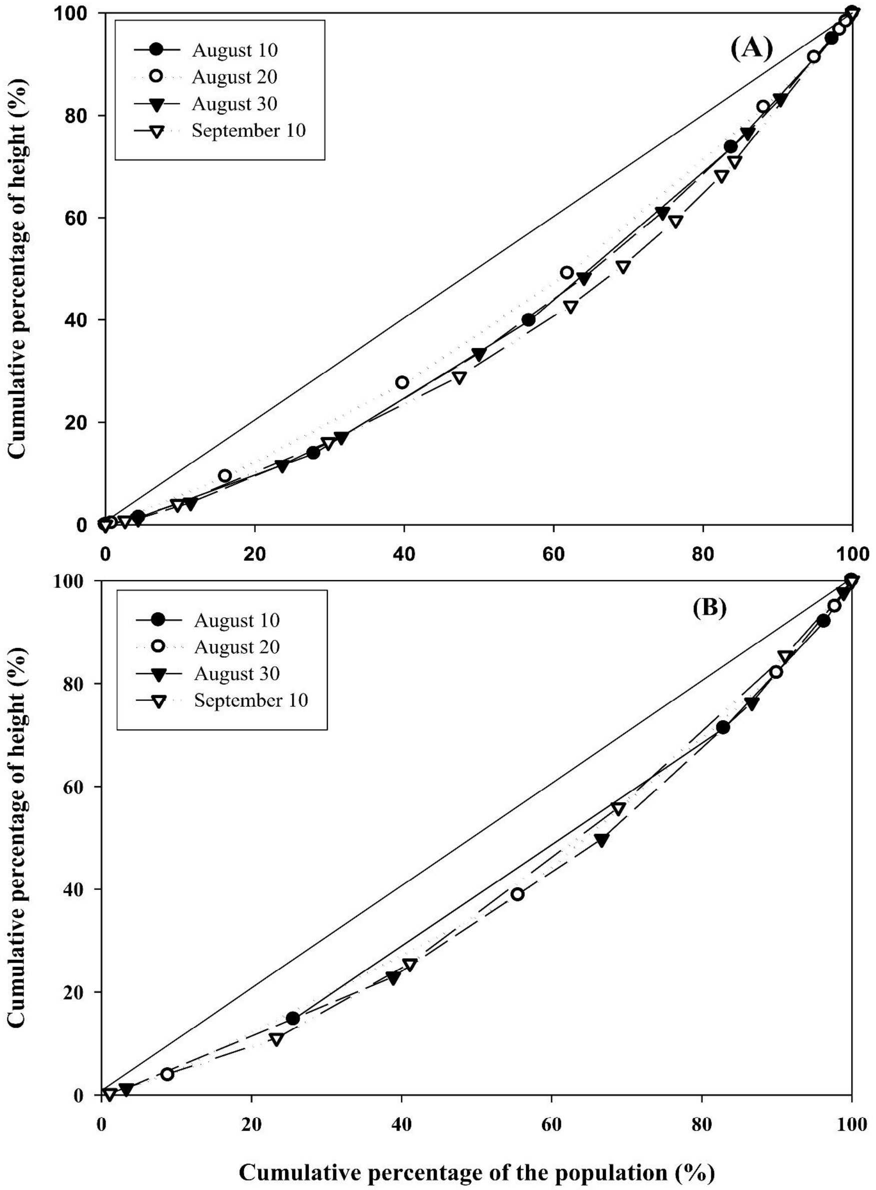

Figure 4.The Lorenz curve as applied to height in *Zea mays* when grown (A) in monospecific and (B) in competition with *P. capillare* during four successive visits. The area under the diagonal is equal to one-half the value of the Gini coefficinets.

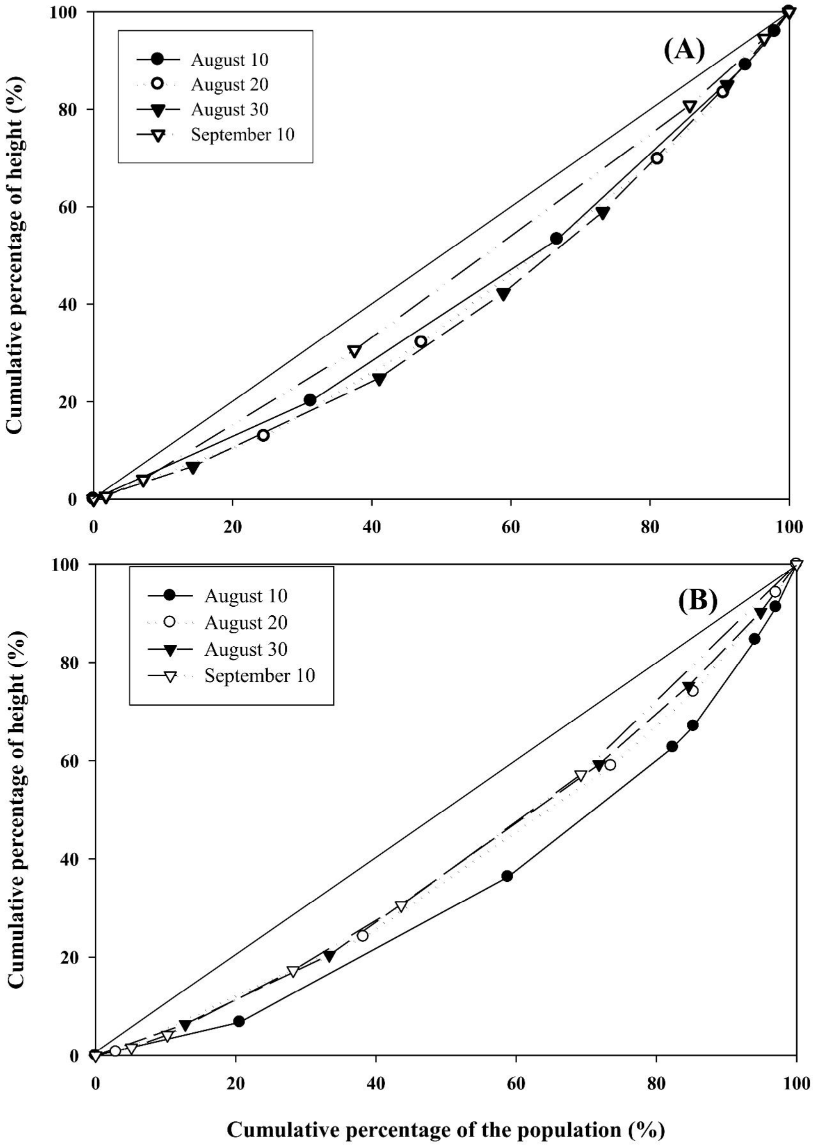

Figure 5. The Lorenz curve as applied to height hierarchies in *Panicum capillare* (A) when grown in monospecific (B) in competition with *Zea mays* during different visits. The area under the diagonal is equal to one-half the value of the Gini coefficients.

Table 1. Effect of competition on size hierarchies in *Zea mays* and *Panicum capillare* grown in monospecific stands and in competition.

Visits	Trt	n	SK		KR		G′	SE	G′ CI	
			Lower	upper	lower	Upper			lower	upper
1	*Z.mays* alone	111	0.605	1.303	-0.95	0.82	0.128	0.0003	0.0006	0.0017
2		118	0.478	1.179	-0.93	0.796	0.089	0.0002	0.0003	0.0012
3		114	0.621	1.348	-0.85	1.216	0.115	0.0003	0.0005	0.0015
4		114	0.702	1.379	-0.83	1.081	0.131	0.0003	0.0006	0.0017
1	*Z.mays/ P. capillare*	82	0.677	2.225	-0.65	2.225	0.125	0.0005	0.0007	0.0025
2		90	0.631	1.507	-0.76	2.043	0.126	0.0004	0.0006	0.0022
3		90	0.632	1.197	-0.63	1.387	0.133	0.0004	0.0007	0.0022
4		90	0.508	1.255	-1.06	0.691	0.118	0.0004	0.0006	0.0021
1	*P. capillare alone*	48	0.353	1.466	-1.18	1.66	0.116	0.0001	0.0006	0.0044
2		54	0.53	1.493	-0.99	1.675	0.186	0.0009	0.0018	0.0052
3		56	0.398	1.383	-1.26	1.057	0.129	0.0008	0.0008	0.0038
4		56	0.175	1.091	-1.22	0.598	0.073	0.0007	0.0001	0.0028
1	*P. capillare/ Z. mays*	34	0.799	2.579	-0.64	7.404	0.196	0.0021	0.002	0.0104
2		34	0.45	1.809	-1.21	3.377	0.143	0.0019	0.0005	0.0079
3		39	0.371	1.568	-1.17	2.327	0.126	0.0014	0.0005	0.006
4		39	0.159	1.278	-1.49	0.869	0.120	0.0013	0.0058	0.159

Visits = 1: August 10, 2: August 20, 3: August 30 and 4: September 10; n= total number of individuals of *Zea mays*/ *Panicum capillare* per treatment with four replicates; SE = standard error of Gini values; SK = skewedness; KR = kurtosis; G′ = unbiased Gini coefficient, G′ CI = 95% confidence interval of G′ were obtained from the “bootstrapping” procedure.

Table 2. Summary of repeated ANOVA for *Zea mays* and *Panicum capillare* plant height as grown in monoculture and in competition at different visits.

Source	DF[1]	Mean square	F-value	Prob.	Adjusted Prob> F	
					G-G[2]	H-F
(a) Between subject effects						
Plant source	3	226436.83	224.814	0.0001		
Error	287	1007.22				
(b) Within subject effects						
Time	3	3999.73	5.902	0.001	0.02	0.001
Time x Plant source	9	1377.54	2.033	0.036	0.0001	0.0001
Time	287	677.70				

1 = DF = degrees of freedom

2 = The Greenhouse and Geisser epsilon is a multiplicate factor by which the number of degrees of freedom of the F test for time-related effects are reduced in order to take the autocorrelation and hetero-scedasticity over time into account (Dutilleul 1998). The G-G (Greenhouse-Geisser) and H-F (Huynh-Feldt) adjustment values are also shown G-G= Greenhouse-Geisser Epsilon = 0.871 and H-F = Huynh-Feldt Epsilon = 0.925 and Lower-bound 0.333.