

Human Activity and State Policy Analysis on Aeolian Desertification in China

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Abstract: Aeolian desertification is often caused by excessive human activities in Northern China. Excessive human activities are often caused by the unreasonable state policies. The expansion of aeolian desertification in northern China during different historical periods is related to the growth of human population and changes in state policy. Rapid expansion of population accelerated the reclamation of grasslands for farmlands, and so accelerated the aeolian desertification process. Certain state policies encouraged the peasant to pursue short-term economic gain via over-grazing, over-cropping and over-logging in state-owned lands, resulting in severe aeolian desertification. Nonetheless, in several typical areas in northern China, aeolian desertification has reversed during the past 5 years, due to the application of new policies to reduce the human activities and to protect the ecological environment in these areas. Because human activities and state policies can dramatically change land-use patterns, abruptly destroy land cover within a short period, and accelerate aeolian desertification, analysis of human activities and the development of appropriate state policies are very important to combat aeolian desertification in China.

Key words: Aeolian Desertification, human activity, state policy, Northern China.

Desertification is one of the most serious environmental and socioeconomic problems facing the world today, which is also causing poverty and migration (Arrow *et al.*, 1995; Portnor and Safriel, 2004). About two-thirds of the countries in the world, one-fifth of the global population and one-fourth of the earth's land surface are now affected by desertification, with a direct economic loss of about USD 42.3 billions per year. In China, desertification causes heavy losses, especially in northern China, including Xinjiang, Inner Mongolia, Tibet, Gansu, Qinghai, Shaanxi, Ningxia, and Hebei provinces (autonomous regions), which together cover 98.45% of the total desertified land in the country (Zhu, 2006).

Aeolian desertification, resulting mainly from human activities in the arid, semi-arid and some sub-humid regions, is the main type of desertification in northern China (Wang *et al.*, 2004). The average rate of expansion of the land affected by desertification between 1955 and 1975 was 1560 km² year⁻¹, which increased to 2100 km² year⁻¹ between 1976 and 1987, and 3600 km² year⁻¹ between 1988 and 2000. In the year 2000, it covered 385,700 km² (Wang *et al.*, 2004). Apart from affecting the socioeconomic development of China's northern arid areas, Aeolian desertification has also affected both environment and human life in northern and eastern China. The direct economic loss due to aeolian desertification is more than USD 6.75 billion

per year, threatening nearly 170 million population of the region (China News, 2003).

Although there are many views on the causes of aeolian desertification, the general conclusions is that over-grazing, over-cultivation, over-cutting, overuse of water, etc., have accelerated aeolian desertification in the last five decades (Zhu *et al.*, 1989; Davis, 2005; Fan and Zhou, 2001; Komatsu *et al.*, 2005; Zhao *et al.*, 2005; Micael, 2000). This paper analyzes the relationship between aeolian desertification process and human activity in China, and suggests measures for combating it.

Human Activity and Aeolian Desertification

How did human activity impact aeolian desertification?

In historical time, rotational grazing was the main land use type in the arid or semi-arid regions of northern China. Human interference on the grassland was negligible, because of small population and extremely low productivity. There was no obvious aeolian desertification in that period. The land to the north of Great Wall was mainly used for pasture, while that to the south was used for farming. During Qing Dynasty (1616-1911), owing to the increasing population, the government encouraged people to reclaim grassland for farming to alleviate the increasing

is to say, it decreased by 10,810 km² or 17.7% during 1987-2000 (Wang *et al.*, 2004). From 2000 to 2005, although the aeolian desertified area in Horqin sandy land did not show obvious change, but the moderately, severely and very severely desertified areas decreased by 195.0 km², 313.8 km² and 145.6 km², respectively, and the slightly aeolian desertified area increased by 635.8 km² (Li *et al.*, 2007), which indicate a gradual reversal of trend due to the state policies mentioned above.

Conclusion

Human activities and state policies can dramatically change land-use patterns. Therefore, it is important to analyze the human activities and implement appropriate state policies to combat aeolian desertification in China. The key questions to be answered are: (a) why do the long-term efforts on aeolian desertification control have achieved less success, (b) where the crux of the problem lies, and (c) how to resolve them. All these questions need to be reconsidered and reexamined, and for addressing the following three issues: (1) how to improve farmers' income under the current environmentally helpful policies, (2) how to adjust the current policies to protect environment and to combat aeolian desertification with the economy developing, and (3) what kind of policies can lead to sustainable development in the aeolian desertified area in northern China.

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References

- Ao, R.Q. 2003. Variance and innovation of the grassland property right systems in China. *Inner Mongolia Social Science* 24: 116-120 (in Chinese).
- Arrow, K., Bolin, B., Costanza, R., Dasgupta, P., Folke, C., Holling, C. S., Jansson, B.O., Levin, S. 1995. Economic growth, carrying capacity, and the environment. *Science* 268: 520-521.
- Chen, J.H., Wei, B.G. and Su, D.X. 2004. *Sustainable Development Stratagem and Countermeasures of the Farming and Grazing Interlaced Zone*. Chemical Industry Press, Beijing, pp. 15-26 (in Chinese).
- China News 2003. The direct economic loss by aeolian desertification is more than 54 billion Chinese Yuan per year (<http://www.chinanews.com.cn/n/2003-03-27/26/287930.html>) (in Chinese).
- Davis, D.K. 2005. Indigenous knowledge and the desertification debate: problematising expert knowledge in North Africa. *Geoforum* 36: 509-524.
- Dong, G.R., Li, C.Z., Jin, J., Gao, S.Y. and Wu, D. 1987. Some results of the simulant experiment on wind erosion soil in wind tunnel. *Chinese Science Bulletin* 32: 1703-1709.
- Dong, Z.B., Chen, W.N., Dong, G.R., Yang, Z.T. and Li, Z.S. 1995. Quantitative relationship between soil erosion by wind and surface structure destruction. *Chinese Science Bulletin* 40: 492-496.
- Fan S.Y. and Zhou, L.H. 2001. Desertification Control in China: Possible Solutions. *Ambio* 30: 384-385.
- Guo, S.L., Du, G.Y. and Wang, Z.J. 1995. *Study on Environment Restoration and Agriculture Development of the border area of Shanxi, Shaanxi and Inner Mongolia in China*. China Science and Technology Press, Beijing, pp. 33-63 (in Chinese).
- Han, J.G., Sun, Q.Z. and Ma, C.H. 2004. *Sustainable Development Technology of Agriculture and Stockbreeding of the Farming and Grazing Interlaced Zone*. Chemical Industry Press, Beijing, pp. 12-20 (in Chinese).
- Komatsu, Y., Tsunekawa, A. and Ju, H. 2005. Evaluation of agricultural sustainability based on human carrying capacity in drylands - a case study in rural villages in Inner Mongolia, China. *Agriculture, ecosystems & environment* 108: 29-43.
- Li, A.M., Han, Z.W., Huang, C.H. and Tan, Z.H. 2007. Remote sensing monitoring on dynamic of sandy desertification degree in Horqin sandy land at the beginning of 21st century. *Journal of Desert Research* 27: 546-551 (in Chinese).
- Liu, Y.Z., Dong, G.R. and Li, C.Z. 1992. Study on some factors influencing soil erosion by wind tunnel experiment. *Journal of Desert Research* 12: 41-49 (in Chinese).
- Micael, C.R. 2000. Is Northern China winning the battle against desertification? Satellite remote sensing as a tool to study biomass trends on the Ordos plateau in semi-arid China. *Ambio* 29: 468-476.
- Portnor, B.A. and Safriel, U.N. 2004. Combating desertification in the Negev: dryland agriculture vs. dryland urbanization. *Journal of Arid Environments* 56: 659-680.
- Wang, T. (Chief Editor) 2003. *Desert and Desertification in China*. Hebei Science and Technology Publishing House, Shijiazhuang, Preface, 3-4 (in Chinese).
- Wang, T., Wu, W., and Xue, X. 2004. Temporal and spatial changes of desertified land in Northern China in the past 50 years. *Acta Geographica Sinica* 59: 203-212 (in Chinese).
- Wang, T., Wu, W., Xue, X., Sun, Q.W. and Chen, G.T. 2004. Study of spatial distribution of sandy desertification in north China in recent 10 years. *Science in China Ser. D Earth Sciences* 47: Supp. 1, 78-88.

- Yang, C., Chang, X.L., Zhao, X. and Zhao, A.F. 2004. *Desertification Control and Restoration Technology*. Chemical Industry Press, Beijing, pp. 65-68 (in Chinese).
- Zhu, L.K. (Chief Editor) 2006. *Dynamics of Desertification and Sandification in China*. China Agriculture Press, Beijing, pp. 5-19 (In Chinese with English summary).
- Zhu, Z.D., Liu, S. and Di, X.M. 1989. *Aeolian Desertification and its Control in China*. Science Press, Beijing, pp. 16-38 (in Chinese).
- Zhao, H.L., Zhao, X.Y., Zhou, R.L., Zhang, T.H. and Drake, S. 2005. Desertification processes due to heavy grazing in sandy rangeland, Inner Mongolia. *Journal of Arid Environments* 62: 309-319.

aonla), grasslands (*Lasiurus indicus* and *Cenchrus ciliaris*), grazing lands and crop lands (pearl millet and arid legumes i.e., moth, mung bean and clusterbean, based cropping system) are the dominant land uses in the farm. Surface soil samples (0-20 cm depth) representing all the land uses were collected (during 2005-2006), and processed for various laboratory determinations. Soil pH was determined using 1:2, soil:water suspension, whereas OC, available phosphorus and potassium were determined following standard procedures (Jackson, 1973). The available Fe, Mn, Zn and Cu in the soil were extracted with DTPA reagent (Lindsay and Norvell, 1978). The above elements in the extract were determined with the help of atomic absorption spectrophotometer.

Results and Discussion

Soil properties

The soils do not show major textural heterogeneity despite differences in land uses. By and large, sand is the dominant fraction in these soils. In surface soil clay content was 6.8-10.5% and silt was 3.5-6.0%. The water holding capacity was 24-32%. All the soil samples were mildly to moderately alkaline (Table 1). Wide variation was observed in SOC (1.05-3.37 g kg⁻¹) with a maximum under silviculture and minimum under crop fields. Thus the average SOC content in different land uses was low (<0.50%), which could be attributed to the prevalence of high temperature, low rainfall, low level of clay and silt in the soils. High temperature and good soil aeration increases the oxidation of organic matter, reducing the SOC

content in the soils (Meena *et al.*, 2006). Higher SOC under silviculture was because of continuous addition of organic matter and vegetative cover throughout the year that protect SOC from oxidation. Intensive tillage, absence of vegetative cover and lower organic matter addition kept SOC low under the crop fields. The results are similar to those reported by Singh *et al.* (2007) and Pradeep-Kumar *et al.* (2006).

The available phosphorus (Olsen P) ranged between 10.8 and 25.7 kg ha⁻¹, with a maximum average value of 20.5 kg ha⁻¹ under crop fields, followed by orchards (19.4), agroforestry system (15.7), with least in grazing lands (12.2 kg ha⁻¹). Continuous addition of phosphate fertilizers in crop fields and orchards (ber and aonla) increased its availability, while no application of phosphorus in silviculture and other systems resulted in lower soil phosphorus status. These results are similar to those of Ransmussen and Douglas (1992) and Pradeep Kumar *et al.* (2006). Keeny *et al.* (2002) reported an increase in available P due to continuous cultivation in Frazer valley of Canada. The available K varied markedly under different land uses and ranged between 213 and 398 kg ha⁻¹ (Table 1). The maximum average available K was under silviculture (316 kg ha⁻¹) followed by grazing land 289 kg ha⁻¹ and was minimum in crop fields 257 kg ha⁻¹. The lower K in soil in crop fields may be due to less application of potassic fertilizers and its removal from the soil by crops. Loss of K in croplands has also been reported in Canada (Keeny *et al.*, 2002). In contrast probably less K removal by plants maintained a comparatively higher K status in soils of

Table 1. pH and nutrients in the soils under different land use systems

Land use	pH	OC (g kg ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Cu (mg kg ⁻¹)
Silviculture	8.2-8.4	1.63-3.37 (2.50)	10.8-18.5 (12.8)	257-398 (316)	6.2-8.8 (7.2)	10.4-15.5 (12.2)	1.4-4.8 (2.7)	2.1-4.4 (2.7)
Agroforestry	8.2-8.5	1.41-2.07 (1.74)	14.8-19.2 (15.7)	228-321 (286)	6.2-7.2 (6.7)	11.8-15.4 (13.7)	1.6-2.4 (2.0)	1.8-2.7 (2.3)
Grasslands	8.1-8.3	1.52-2.39 (1.85)	11.5-15.4 (13.5)	248-345 (286)	5.8-8.4 (6.6)	11.3-16.5 (13.6)	1.2-2.5 (1.8)	1.5-2.4 (2.1)
Grazing land	8.2-8.3	1.42-2.39 (1.78)	11.5-14.8 (12.2)	248-345 (289)	5.2-7.8 (6.7)	10.6-12.2 (11.5)	1.5-2.1 (1.8)	1.6-2.4 (2.1)
Orchards	8.2-8.4	1.30-1.85 (1.63)	11.7-22.2 (19.4)	225-318 (265)	5.7-8.5 (6.9)	9.4-17.2 (12.8)	1.5-2.5 (2.1)	1.7-3.2 (2.5)
Crop field	8.2-8.4	1.05-1.96 (1.52)	15.2-25.7 (20.5)	213-298 (257)	5.2-8.5 (6.2)	9.9-15.4 (11.8)	1.2-2.4 (1.7)	1.2-2.2 (1.6)

Figures in parenthesis indicate the mean values.

Table 2. Correlation coefficient (r) between soil organic carbon and other soil properties under different land use systems

Land use	P (kg ha ⁻¹)	K (kg ha ⁻¹)	Fe (mg kg ⁻¹)	Mn (mg kg ⁻¹)	Zn (mg kg ⁻¹)	Cu (mg kg ⁻¹)
Silviculture	0.697**	0.643*	0.564*	0.277	0.652*	0.624*
Agroforestry	0.544	0.582*	0.315	0.245	0.243	0.621*
Grasslands	0.638*	0.782**	0.563*	0.660*	0.155	0.704*
Grazing land	0.625*	0.694**	0.563*	0.292	0.123	0.728**
Orchards	0.284	0.392	0.299	0.470	0.342	0.305
Crop field	0.304	0.413	0.406	0.461	0.382	0.469

* Significant at 5% level of significance; ** Significant at 1% level of significance.

silviculture system. Several other workers also reported similar results in arid soils under silviculture and grasses (Dhir and Gajbhiye, 1973).

Significant variation in micronutrient (mg kg⁻¹) content was observed among the soils under different land uses. In general soils under silviculture recorded highest average concentrations of these micronutrients (Table 1), followed by orchards, agroforestry, grasslands; and grazing lands, and the minimum was under crop fields. The lower content of these micronutrients in crop fields could be due to their removal by the crops. Based on the critical limits for Fe, Mn, Zn and Cu as 2.0, 5.0, 0.60 and 0.20 mg kg⁻¹, respectively, as suggested by Takkar and Randhawa (1978), the soils under different land use systems in the present study appear to be adequate. Similar observations were also made by Joshi and Dhir (1983) and Sharma *et al.* (1985) regarding the micronutrients status in arid soils of Rajasthan.

Relationship between organic carbon and available nutrients

The available phosphorus was strongly associated with SOC in soils under different land use systems (Table 2). The highest correlation coefficient (r) between available P and SOC was observed for soils under silviculture (r = 0.697) followed by grasslands (r = 0.638) and the least in soil under orchard (r = 0.284). It suggested that available P was highly dependent on the SOC in silviculture and grasslands followed by soils under grazing lands and minimum in orchards. Available K showed a positive correlation with SOC under all land use systems. The highest correlation was observed for soils under grassland (r = 0.782), followed by grazing land (r = 0.694).

Positive correlation between SOC and the micronutrients (DTPA extractable Fe, Mn, Zn and Cu) in all the land uses was also noticed. The

available Fe was positively and significantly correlated with SOC in soils under silviculture (r = 0.564), followed by grasslands and grazing land (r = 0.563). The Mn content in these soils was positively correlated with SOC under all the land uses and highest correlation was observed in grasslands (r = 0.660). The positive and significant correlation was observed between SOC and Zn in silviculture and SOC and Cu in grasslands, grazing lands, silviculture and agroforestry, respectively.

The positive correlation between SOC and available major and micronutrients in tree-based systems can be attributed to the continuous addition of organic matter to the soil under natural condition. Addition of organic/inorganic sources of nutrients under crops and orchards may be the main factor leading to the positive correlation between SOC and available P, K, Fe, Mn, Zn, and Cu under these two systems.

It is concluded that most of the soil nutrients were significantly influenced by the differences in land use. Most of the nutrients were higher in tree-based system in soil except available P, which was highest under crop fields. The simple correlation studies showed that SOC was positively correlated with all the above soil properties and had highest correlation with K, Cu and P.

References

- Bhattacharyya, T., Chandran, P., Ray, S.K., Pal, D.K., Venugopalan, M.V., Mandal, C. and Wani, S.P. 2007. Changes in levels of carbon in soils over years of two important food production zones of India. *Current Science* 93: 1854-1863.
- Bhattacharyya, T., Chandran, P., Ray, S.K., Pal, D.K., Venugopalan, M.V., Mandal, C., Wani, S.P., Manna, M.C. and Ramesh, V. 2005. Carbon sequestration in red and black soils of semi arid tropical parts of India: II. Influence of physical and chemical properties of soils. *Agropedology* 17: 16-25.

Table 1. Analysis of variance for combining ability for various traits in pearl millet (diallel study)

Source	df	Plant height (cm)	Days to 50% flowering	Effective tillers/plant	Ear length (cm)	Ear girth (cm)	Ear heads/plot	Dry fodder yield/plot (g)	Biomass/plot (g)	1000-grain weight (g)	Threshing ratio	HI
GCA	5	307.5**	17.8**	0.19**	10.8**	0.18**	524.5**	28300	74055**	1.00**	0.0046**	0.0015
SCA	15	34.2	5.3**	0.11**	3.6**	0.04**	148.9**	55155**	141886**	0.90**	0.0028**	0.0036**
ERROR	40	69.9	1.5	0.03	1.1	0.01	26.6	16783	18064	0.01	0.0006	0.0007
GCA:		8.9	3.3	1.73	3.00	4.50	3.5	0.51	0.52	1.11	2.00	0.416
SCA												

*, ** Significant at P = 0.05, 0.01, respectively.

spacing. Fertilizer dose of 20 kg N ha⁻¹ and 20 kg P ha⁻¹ were given at the time of planting, and remaining 20 kg N ha⁻¹ was top-dressed 25 days after seedling emergence. During the cropping season the crop received a rainfall of 265 mm, of which 214 mm rainfall was received in the month of July itself, while 46.4 mm was received in August and only 3 mm rainfall was received in September. Thus the crop experienced severe terminal stress resulting to reduced grain yield.

In both the trials data were recorded on plant height (cm), days to 50% flowering, effective tillers/plant, ear length (cm), ear girth (cm), number of ear heads/plot, grain yield/plot (g), dry fodder weight/plot (g), total biomass/plot (g) and 1000-grain weight (g). Harvest index (HI) and threshing ratio were also calculated using the primary data. Data from both diallel and line x tester studies were subjected to analysis of variance. Data from diallel set were analyzed following method II and

Table 2. Mean performance and general combining ability effects (in parenthesis) of parents in diallel study in pearl millet

	CZI 962	CZI9613-1	CZI 96/1604	CZI 1676-2	CZI 98/6	CZI 98/9	SE gi ±
Plant height (cm)	158 (4.61*)	142 (-3.93)	143 (-4.31)	159 (9.99**)	136 (-6.10**)	142 (-0.26)	2.31
Days to 50% flowering	51 (2.21**)	48 (0.21)	49 (-0.96*)	43 (-1.13**)	50 (1.25**)	45 (-1.58**)	0.39
Effective tillers/plant	1.22 (-0.02)	1.25 (0.16*)	1.63 (0.21**)	1.07 (-0.07)	1.04 (-0.01)	1.07 (-0.19**)	0.05
Ear length (cm)	23 (0.39)	22 (-0.90*)	21 (-1.94**)	23 (0.81*)	25 (0.89*)	24 (0.76*)	0.34
Ear girth (cm)	2.6 (-0.06)	2.4 (-0.11**)	2.3 (-0.16**)	2.9 (0.25**)	2.5 (-0.03)	2.5 (0.09*)	0.04
Ear heads/plot	52 (2.24)	39 (3.15*)	66 (12.86**)	38 (-1.85)	37 (-6.01**)	31 (-10.39**)	1.61
Grain yield/plot (g)	247 (-31.74*)	338 (-3.11)	238 (20.18)	340 (77.35**)	165 (-38.07**)	300 (-24.61*)	12.20
Dry fodder yield/plot (g)	1033 (-20.14)	1200 (34.03)	1100 (71.53*)	1200 (42.36)	750 (-86.81*)	1300 (-40.97)	31.51
Biomass/plot (g)	1280 (-51.87)	1538 (30.92)	1338 (91.71*)	1540 (119.71**)	915 (-124.87**)	1600 (-65.58*)	33.17
1000-grain weight (g)	7.7 (-0.47**)	6.1 (-0.35**)	4.9 (0.31**)	5.1 (0.15**)	5.8 (-0.16**)	6.2 (0.52**)	0.02
Threshing ratio	0.53 (-0.03)	0.66 (0.01)	0.53 (0.00)	0.56 (0.01)	0.47 (-0.02)	0.60 (0.03)	0.02
HI	0.20 (-0.01*)	0.22 (0.01*)	0.18 (-0.01*)	0.23 (0.03**)	0.18 (-0.01*)	0.19 (0.01*)	0.005

*, ** Significant at P = 0.05, 0.01, respectively.

Cross	Grain yield (kg ha ⁻¹)			Days to 50% flowering			Effective tillers/plant		
	Mean	SCA	Heterosis (%)	Mean	SCA	Heterosis (%)	Mean	SCA	Heterosis (%)
CZI 96/1604 x CZI 98/6	777	330.2**	285.3	43	-3.10**	-13.8	1.5	-0.01	12.11
CZI 9613-1 x CZI 1676-2	755	216.1**	122.7	44	-0.23	-3.6	2.4	0.82**	103.10
CZI 96/1604 x CZI 1676-2	625	62.5	116.0	44	0.27	-6.1	1.5	-0.13	7.10
CZI 962 x CZI 1676-2	623	113.1**	112.5	45	-1.23	-4.9	1.4	0.07	24.70
CZI 1676-2 x CZI 98/9	611	93.9*	127.1	42	-0.43	-4.9	1.1	-0.08	3.30
CZI 9613-1 x CZI 96/1604	508	27.0	76.5	43	-2.01*	-11.4	2.0	0.22*	41.33
SE (sij) ±		36.2			1.02			0.10	

model I of Griffing (1956), while data from line x tester set was analyzed using method of Kempthorne (1957).

In diallel study, analysis of variance for combining ability (Table 1) revealed significant variances due to general combining ability (GCA) of parents for all traits except for dry fodder yield and HI, and significant specific combining ability (SCA) variances for all traits except for plant height. Thus both kinds of gene effects, additive as well as non-additive, were important in controlling the inheritance of most of the traits. The GCA:SCA ratio, however, indicated greater role of additive gene effects for plant height, days to 50% flowering, ear length, ear girth, number of ear heads/plot and threshing ratio, and non-additive gene effects

for grain yield, dry fodder yield, biomass and HI, while both additive and non-additive gene effects were equally important for effective tillers/plant and 1000 grain weight. Almost similar gene effects for these traits have been reported by Talukdar and Prakash Babu (1999) and Karale *et al.* (1998). Mean performance and GCA effects resulting from diallel study for various traits (Table 2) revealed that CZI 1676-2 had the highest mean performance followed by CZI 9613-1 and CZI 98/9. This parent was also earliest to flower and had significantly high GCA effects for plant height, days to 50% flowering, ear length, ear girth, biomass, HI and 1000 grain weight. CZI 96/1604 had the highest mean performance and GCA for effective tillers/plant and also showed high GCA effects for number of ear-heads, dry fodder yield, biomass and 1000 grain weight. CZI 98/6 had

Source	df	Plant height (cm)	Days to 50% flowering	Effective tillers/plant	Ear length (cm)	Ear girth (cm)	Ear heads/plot	Grain yield/plot (g)	Dry fodder yield/plot (g)	Biomass /plot (g)	1000-grain wt. (g)	Threshing ratio	HI
FEMALE (F)	3	547.1**	39.5**	0.106**	102.3**	0.40**	39.27	114524**	153750*	490467**	15.39**	0.038**	0.0008
MALE (M)	5	370.8**	39.4**	0.081*	16.9**	0.21	274.65**	27748**	69555	108622	5.91**	0.006	0.0096**
F x M	15	49.2	4.8	0.045	5.6	0.05	84.26**	22868**	45055	113961	2.41**	0.012*	0.0023
ERROR	46	104.2	3.3	0.025	5.2	0.04	30.68	7615	47530	75961	0.007	0.006	0.0026
GCA: SCA		1.38	4.6	1.07	25.2	3.5	0.27	0.63	5.38	0.98	0.69	0.01	0.01

the highest grain yield, SCA and per cent heterosis over mid parent, and was followed by ICMA 94555 x CZI 1676-2, ICMA 97111 x CZI 1676-2, ICMA 97111 x CZI 96/1604 and ICMA 94222 x CZI 9613-1. These hybrids recorded 42.9% to 4.5% higher grain yield over the earliest flowering (42 days) check hybrid HHB 67, hence were suitable for arid areas having short moisture availability period.

Diallel analysis thus identified superior pollinators having high GCA and also crosses having high SCA and high heterosis, involving parents with high GCA. These crosses because of their ability to throw better progenies can be used for the development of new pollinators suitable for hybrid breeding programme, while line x tester study identified suitable male and female parents along with potential hybrids for this region. Thus by using both diallel and line x tester analyses together, it was possible to generate

not only useful information about ability of parents and crosses for developing new pollinators but also potential hybrids.

References

- Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Sciences* 9: 463-493.
- Karale, M.U., Ugale, S.D., Suryanvanshi, Y.B. and Patil, B.D. 1998. Studies on combining ability for grain yield and its components in pearl millet. *Indian Journal of Agricultural Research* 32: 1-5.
- Kempthorne, O. 1957. *An Introduction to Genetic Statistics*. John Wiley & Sons Inc., New York.
- Talukdar, B.S. and Prakash Babu, P.P. 1999. Identification of parents and crosses for breeding improved pearl millet restorer. *Indian Journal of Genetics and Plant Breeding* 59: 163-174.