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# Evaluation of Genotype X Environment Interaction for Grain Yield Stability of Pearl Millet (*Pennisetum glaucum* (L) R. Br) Genotypes across Five Localities of Niger

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**Abstract** **Original Research Article**

Multi-environment trials were conducted during rainy season (June-October, 2015) at four locations of Niger country (latitude 13°29' N, Longitude 2°10' E). A large number of improved varieties exist in an uncontrolled way. These varieties show better yields in favorable climatic conditions but their adaptations are fragile at the least abiotic constraint. Stable performance of pearl millet cultivars under diverse ecological zones is vital to maintain the necessary increase in food production. The objective of this work is to estimate the Genotype by Environment Interaction (GEI) for grain yield in ten pearl millet varieties and to identify stable and promising varieties for general and specific adaptation across different agroecosystems in Niger. The experiments were laid out in a randomized complete block design with four replications. The phenological, morphological and agronomic traits were evaluated during vegetation and at harvest. Analysis of variance showed highly significant difference between the varieties (p=0.002) and between localities (p=0,001). However, the interaction genotype by environment (GEI) is relatively of low significance (p=0,123). Proportions of variance explained respectively by genotypes, environment and Genotypes x environment were 12.74%; 65.98% and 21.28% of total variation. This indicates a strong effect of the environment on genotypes grain yield. Among ten varieties the variety MI1054 showed the highest average grain yield (1.462 tons per ha) but the variety MI1363 showed the best stability across environments with 1.265 tons per ha of grain yield. The varieties GB8735 and H-80-10-GR showed high performance for the region of Magaria, when HKP is better for Niamey.
**Keywords**: GxE interaction, Pearl millet, genotypes evaluation, Niger.


## INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L) R. Br.) is an important staple food security crop in Niger. It covers more than 7 million hectares, but production is insufficient due to adverse biotic and abiotic stress, coupled with the cultivation of open pollinated varieties. The strong growth of the population together with current climate change were serious threats to food security in poor countries where agricultural production is closely linked to rainfall [1-3]. Adaptation to climate change through innovative technologies is a mandatory passage to provide a better chance for food security in such countries [4, 5]. In case of pearl millet (staple crop in Niger), a large number of varieties produced by agricultural research, each with its advantages and disadvantages are currently uncontrolled in circulation throughout the country. The elite genetic material has more yield potential in favourable conditions but its adaptation is very low to severe drought conditions, as is the case frequently in Niger [6, 7]. It is essential to determine the adaptability of these different varieties to the different agro-ecological zones of Niger [8]. Several numbers of methods for testing adaptability of a variety over diverse environments are now available [9, 10]. A variety is considered to be more adaptive or stable if it has a high mean yield but low degree of fluctuation in yielding ability when grown over diverse environments. Knowledge of GEI is advantageous to have a cultivar that gives consistently high yield in a broad range of environments, what can contribute to increase total food production. Agronomic research has resulted in the development of some high yielding varieties of pearl millet, but experimental stations are mostly concentrated in regions, where rainfall is relatively high. A considerable variation in grain yield of released varieties is observed between these experimental station and farms. However, studies on the effects of GEI on pearl millet grain yield are quite few in Niger.

Assessing any genotype performance without including its interaction with the environment is incomplete and limits the accuracy of measured parameter estimates. Therefore, this paper is designed to study the magnitude and nature of G x E interaction for pearl millet varieties grown at different environments and to identify stable genotypes that can give high grain yield under a wide range of growing conditions across the country.

## MATERIALS AND METHODS

Multi-environment trials were conducted during rainy season (June-October, 2015) at four locations, namely Maradi, Niamey, Tillaberi and Magaria, each one corresponds to one of the main agro-ecological zones of Niger country, at latitude 13°29' North and longitude 2°10' Est (Table 1). These locations are indicated in red dot on the map (Figure 1). The three sites of Magaria, Maradi and Niamey lie between the 450 and 550 mm isohyets. Only the site of Tillaberi is a little drier, between 450 and 350 mm. The regions of Tillaberi and Niamey are normally warmer, and potentially have the highest evapotranspiration rate of the four regions. On the other hand, the regions of Magaria and Maradi are relatively cooler (Table 1). The experiments were laid out in a randomized complete block design with four replications. The experiment unit was a six-row plot of 10-meter-long, spaced at 1 meter on the line and between the lines. Seeds were sown manually along rows in 5 to 10 cm deep holes, 10 to 20 seeds per hole. Inorganic fertilizer (NPK 15-15-15) at the dose of 100 kg per hectare was applied before sowing and incorporated by manual plowing. Nitrogen fertilizer was applied at a total dose of 100 kg per hectare in the form of urea, one part, 3 weeks after emergence and the rest before heading. Seeds were sown by hand dibbling. Weeding was conducted when needs. All the recommended agronomic practices and need based plant protection measures were adopted. Crops were thinned out to three plants per poquet, two weeks after crop emergence. At different growth stages data were collected from the four middle poquets of the two middle rows, for number of tillers, number of ears, plant height and grain yield. Analysis of variance was carried out by SPSS software. The genetic material used in this study is consisted of ten pearl millet (Pennisetum glaucum [L.] R. Br.) Varieties as described in Table 2. Six of them are the best varieties promoted by agricultural extension services and 4 are new varieties developed by the Laboratory of Biotechnology and Plant Improvement of the Institute of Radio-Isotopes of the University of Niamey Niger.

**Table 1: Some climatic and soil characteristics of the four locations**

| Locations | Code | Rainfall (mm) | Temperature | Soil Type | pH |
|---|---|---|---|---|---|
| Lossa | TI | 551.6 | 24-43 | Sandy Clay | Slightly acidic |
| Magaria | MG | 491.7 | 17-43 | Sandy | Acidic |
| Maradi | MI | | 21-43 | Sandy | Acidic |
| Niamey | NY | 452.7 | 22-44 | Sandy | Acidic |

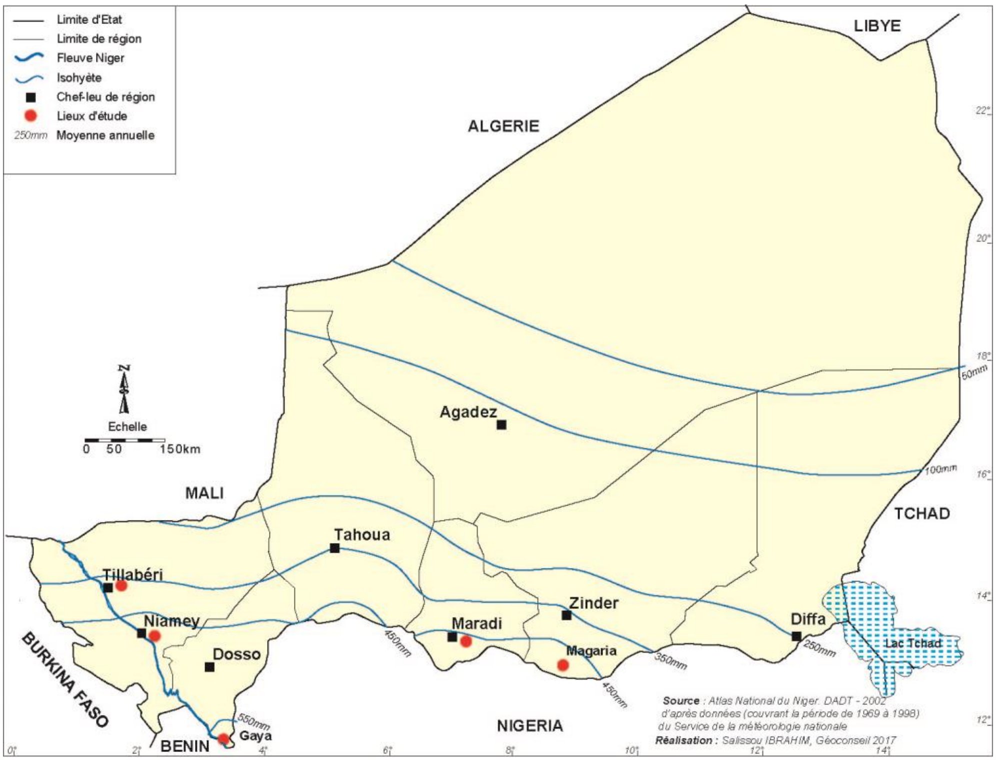


**Fig-1: Experimental localities (in red dot)**

**Table-2: Pearl millet varieties used in the test**

| Number | Variety | Origin | Potential Grain Yield (tons per ha) | Days to maturity |
|---|---|---|---|---|
| 1 | MI 0282 | LABAP-IRI | 1,5 à 2,5 | 90 |
| 2 | MI 1363 | LABAP-IRI | 1,5 à 2,5 | 90 |
| 3 | MI 1272 | LABAP-IRI | 1,5 à 2,5 | 90 |
| 4 | MI 1054 | LABAP-IRI | 1,5 à 2,5 | 90 |
| 5 | HKPiri | INRAN | 1,5 à 2,5 | 90 |
| 6 | ICMVIS99001 | ICRISAT | 1,5 | 95 |
| 7 | Zatib | INRAN | 2 à 2,5 | 90-95 |
| 8 | GB8735 | ICRISAT | 1,5 | 70 |
| 9 | H80-10-GR | INRAN | 2,5 | 80-85 |
| 10 | HKPinran | INRAN | 1,5 à 2,5 | 85-90 |

## Results and Discussion

### Seasonal rainfall of the four locations

Mean annual and monthly temperature and rainfall data of the experimental sites during the 2015 cropping season are presented in table 3. Total rainfall received in 2015 varied between 452.7 mm to 551.6 mm. Tillaberi received more water against Niamey and Magaria, paradoxically. The months of july and august are the most watered. They alone account for 75% of the total annual rainfall. It is also the period when the rain events are the most stable. Fortunately, they correspond (in general) to the period of strong growth and hence of strong water demand for pearl millet crop. These mean monthly values hide in practice large disparities in the daily or weekly distribution of precipitation. This can lead in water deficits that can affect negatively crop development. But the most frequent and most dangerous water stress for pearl millet crop in Niger is as shown in figure 2. The scarcity of rains at the end of the cycle results in a water deficit at the moment when seeds maturation is underway. This results in significant yield losses. This is unfortunately the case in Niger, almost every other year. Early planting in late april to early june remains the only solution, but is becoming increasingly rare.

**Table-3: Monthly rainfall at the five localities**

| | Month | June | July | August | September | October | Annual |
|---|---|---|---|---|---|---|---|
| Locality * | | | | | | | |
| Magaria | | 20.3 | 187.8 | 182.3 | 87.2 | 13.6 | 491.2 |
| Niamey | | 36.4 | 167.1 | 142.0 | 89.8 | 17.4 | 452.7 |
| Tillaberi | | 20.2 | 201.9 | 214.3 | 100.8 | 14.4 | 551.6 |

(*) The rain gauge of the locality of Maradi was failing

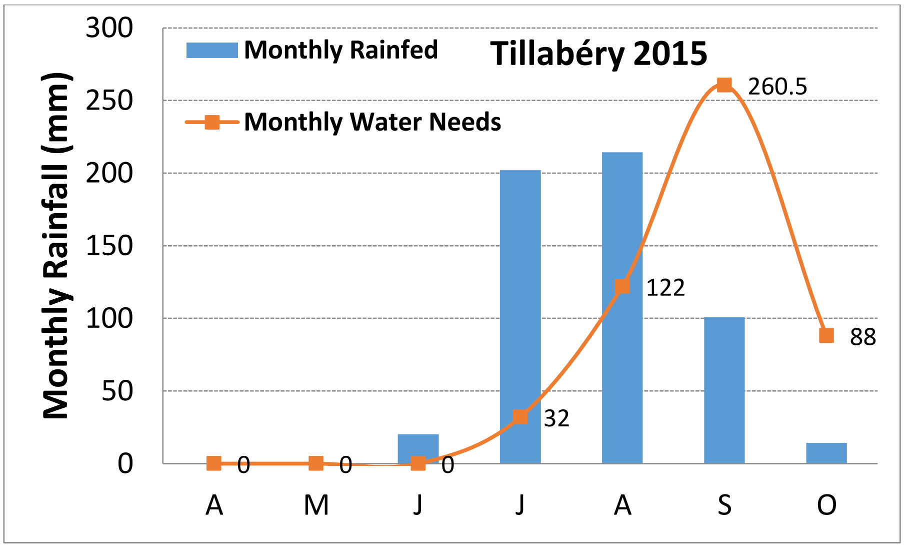


**Fig-2: Monthly rainfall compared to pearl millet water needs in the region of tillaberi in Niger, year 2015**

 

**Grain yields of ten pearl millet genotypes across the four environments**

The grain yield obtained for the four localities are presented in Table 4. The grand mean was 1.252 $tha^{-1}$. Across environment, mean yield of genotypes ranged from 1.728 $tha^{-1}$ (in Magaria) to 0.770 $tha^{-1}$ (in Niamey). This variation could be related to the varying environmental conditions. These values are relatively high, compared to those generally obtained from farmers, as reported by Manyame [11]. There is always a gap of productivity between experimental plots and on-farms fields, which remains a challenge in south Saharian Africa. Recent advances in pearl millet productivity are mainly related to the use of highly productive hybrids [12-14], when open-pollinated varieties are still the most widely used in Niger. Some authors [15], reported higher grain yields in northern Nigeria (1.8-4.4 $tha^{-1}$); Wedajo [16] in Ethiopia 1.5 to 3.3 $tha^{-1}$ and Kanton *et al.* [17] in Ghana 0.713-2.131 $tha^{-1}$. These three countries are much more watered than Niger, highlighting the negative effect of water deficits on pearl millet yield. Pearl Millet is also very sensitive to soil fertility, particularly its richness in organic matter [11] or nitrogen availability [18]. Working on a silty clay loam soil, Obeng *et al.* [19] have observed no significant effect of nitrogen fertilizer on grain yield of several varieties of pearl millet, indicating that pearl millet can be satisfied with modest soil fertility to achieve its growth. All these studies show the sensitivity of pearl millet to environmental conditions and justify the needs of the studies on genotype-environment interaction in order to maximize production of each specific agro-ecological zone.

**Table-4: Mean genotype grain yield by locality (tons per ha)**

| Envir/GEN | MI 0282 | MI 1363 | MI 1272 | MI 1054 | HKP iri | ICMVIS | ZATIB | GB 8735 | H80 10GR | HKP inran | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| MG | 1.764 | 1.759 | 1.4 | 2.054 | 1.604 | 1.768 | 1.728 | 1.556 | 2.237 | 1.41 | 1.728 |
| MI1 | 1.85 | 1.506 | 1.656 | 1.744 | 1.825 | 1.637 | 1.375 | 0.919 | 1.387 | 1.314 | 1.521 |
| MI2 | 1.041 | 1.394 | 1.333 | 1.131 | 0.963 | 1.175 | 0.957 | 0.633 | 0.869 | 1.219 | 1.071 |
| Ny | 0.727 | 0.503 | 0.639 | 1.082 | 0.566 | 0.891 | 0.568 | 0.602 | 0.971 | 1.147 | 0.770 |
| TI | 0.868 | 1.29 | 1.298 | 1.3 | 1.224 | 1.331 | 1.488 | 0.567 | 1.135 | 1.178 | 1.168 |
| Mean | 1.250 | 1.290 | 1.265 | 1.462 | 1.237 | 1.361 | 1.223 | 0.856 | 1.320 | 1.253 | 1.252 |

MG= Magaria; MI1=Maradi1; MI2= Maradi2 ; Ny= Niamey ; TI=Tillaberi

**Relationships between yield and yield components**

The present study showed correlation between pearl millet grain yield and three of the morphological traits known to be principal components determining the yield, including total number of tillers (TlT), number of ears (EP) and tillers eight (LgT). Relationships between pairs of variables studied over the five environments are reported in table 5. Across the ten genotypes, grain yield was positively and highly significantly correlated ($p<0.01$) to all the three studied variables: tillers numbers (R= 0.299), the ears numbers (R= 0.200) and the plant height (R= 0.265). This result is in line with several previous finding in pearl millet [16, 20, 21- 25]. The number of ears is positively and significantly correlated to the total number of tillers, suggesting that these two traits can be selected simultaneously. In the same way, the total number of tillers and the plant height are positively and significantly correlated. In the other hand, the number of ears and the plant height are negatively and significantly correlated. When one of these two traits is improved, antagonistically the other will be affected negatively. This result indicates that the size of the stem decreases the number of fertile stems. This can be explained by the effect of shading which increases with the height of the stem and reaches its maximum effect at the heading.

The plant eight is positively correlated to grain yield. This means that the taller the plants, the more yield they produced and vice versa. This result had been previously reported by Obeng *et al.* [19] on pearl millet. All This information on the correlations between the characteristics of millet plants may be useful for breeders but farmers place early maturity and grain yield as the first criteria in the choice of new varieties of pearl millet. The plant sizes (plant height, ear length and diameter) were in the final order [15].

**Table-5: Combined correlation coefficients between yield and yield components in pearl millet genotypes grown across five environments (Pearson Correlations Coefficient)**

| | PG | EP | TlT | LgT |
|---|---|---|---|---|
| PG | 1 | 0.200** | 0.299** | 0.265** |
| EP | | 1 | 0.302** | -0.153* |
| TlT | | | 1 | 0.518** |
| LgT | | | | 1 |

** Correlation is significant at the 0.01 level; * Correlation is significant at 0.05 levels
PG=Grain Yield; EP=Number of ears; TIT= Number of tillers; LgT= tillers eight

**Genotype by Environment Interaction**

From the total treatment sum of square of the model, 65.98% was attributed to environmental effects, and the rest to genotypic effects (21.28%) and GEI (12.74%) (Table 6). The highly significant mean squares of environment ($P<0.001$) indicated that the environments were diverse, with large differences among means, causing most of the variation in grain yield. This shows the predominant influence of environments on the yield performance of pearl millet genotypes in Niger. This kind of result has already been reported in previous works [9].

The first and the second principal components captured respectively 82.81% and 11.15% of the total variance. They cumulatively explained 93.96% of the variance (Table 7). The cumulative mean square of PCA1 and PCA2 was 15 times that of the residual, suggesting that the two interaction principal components were sufficient to explain GEI in pearl millet grain yield.

The biplot presentation showed a positive correlation for all initial variables with PCA1 axis (figure 3). Genotypes near the origin were non-sensitive to environmental interactive forces; and those distant from the origin were sensitive and had large interactions [26]. Accordingly, genotype MI1272 with score of nearly zero showed stability and small interaction across different environments. This genotype performed well in all environments. Whereas, genotypes GB8735 and H8010GR were highly influenced by the interactive force of environment and sensitive to environmental changes. These varieties (with long projections from the origin) were considered as unstable genotypes. They performed highly in the region of Magaria with respectively grain yield of 1.556 and 2.237 tons per ha. In the same way, variety HKP-INRAN, with grain yield of 1.147 tons per ha showed best adaptation to the region of Niamey. In the middle, some varieties with moderate (but considerable) interaction with environment are MI1363, HKP-IRI, MI0282, MI1054 and ICMVIS99001. They didn't show any clear adaptation to any specific locality. This kind of result is in accordance with previous researchers on different crops [27, 28, 29].

Graphic representations showed that the points for the environments (Figure 4) were more scattered than the points for the varieties. This confirms as in the ANOVA, that the variability due to the environment is higher than the variability due to the varieties. The dispersion of the localities on the biplot shows that the region of Magaria is the one that discriminates better the varieties (in terms of grain yield). This region should be proposed for millet varietal comparison testing. On the contrary, the region of Tillabéri is the one that groups the varieties and that of Niamey, the most restrictive.

**Table-6: Combined ANOVA of grain yield for ten pearl millet genotypes tested in five locations in Niger**

| Source | DF | SS | MS | F (vr) | P | Total SS explained (%) |
|---|---|---|---|---|---|---|
| Genotype | 9 | 4.4104 | 0.4900 | 3.18 | 0.002 | 12.74 |
| Location | 4 | 22.8554 | 5.7138 | 37.07 | <0.001 | 65.98 |
| GenxLocation | 36 | 7.3728 | 0.2048 | 1.33 | 0.123 | 21.28 |
| Residual | 147 | 22.6593 | 0.1541 | | | |

**Table-7: Eigen values of the Principal Component Analysis for grain yield of ten genotypes of pearl millet tested in five locations**

| Component | Initial Eigen values | | |
|---|---|---|---|
| | Total | % of variance | % cumulative |
| PCA1 | 8,28 | 82,81 | 82,81 |
| PCA2 | 1,12 | 11,15 | 93,96 |
| PCA3 | 0,39 | 3,91 | 97,87 |
| PCA4 | 0,21 | 2,13 | 100,00 |

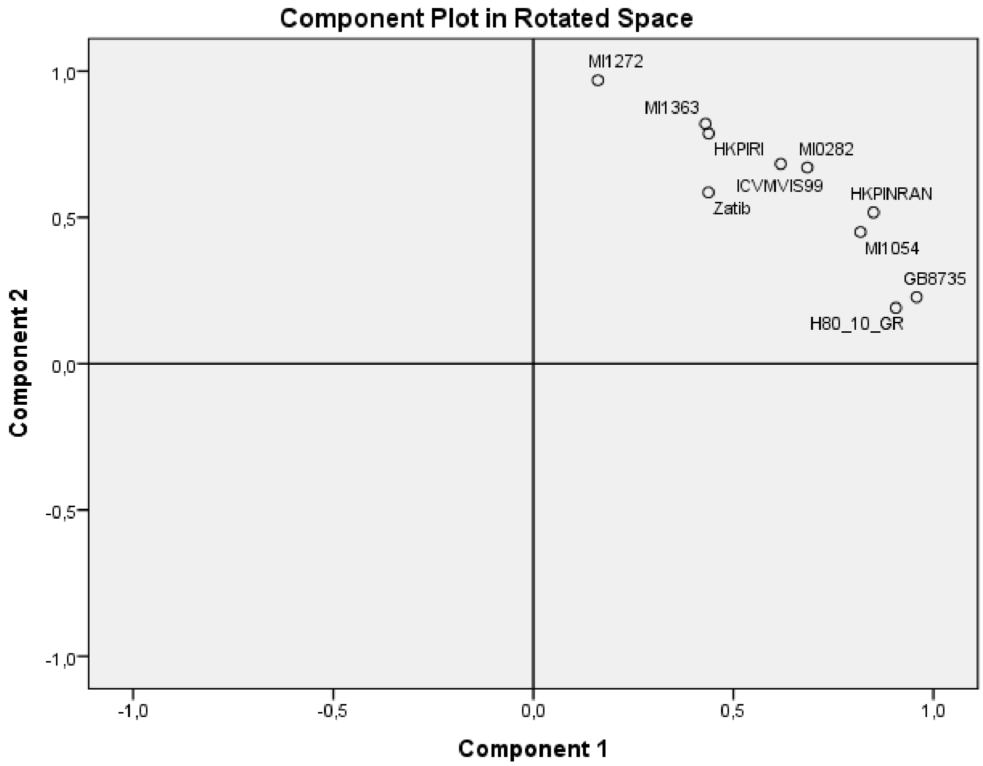


**Fig-3: Scatter plot of first two principal components contributing to 93.96% of total variation for four quantitative characters in pearl millet genotypes**

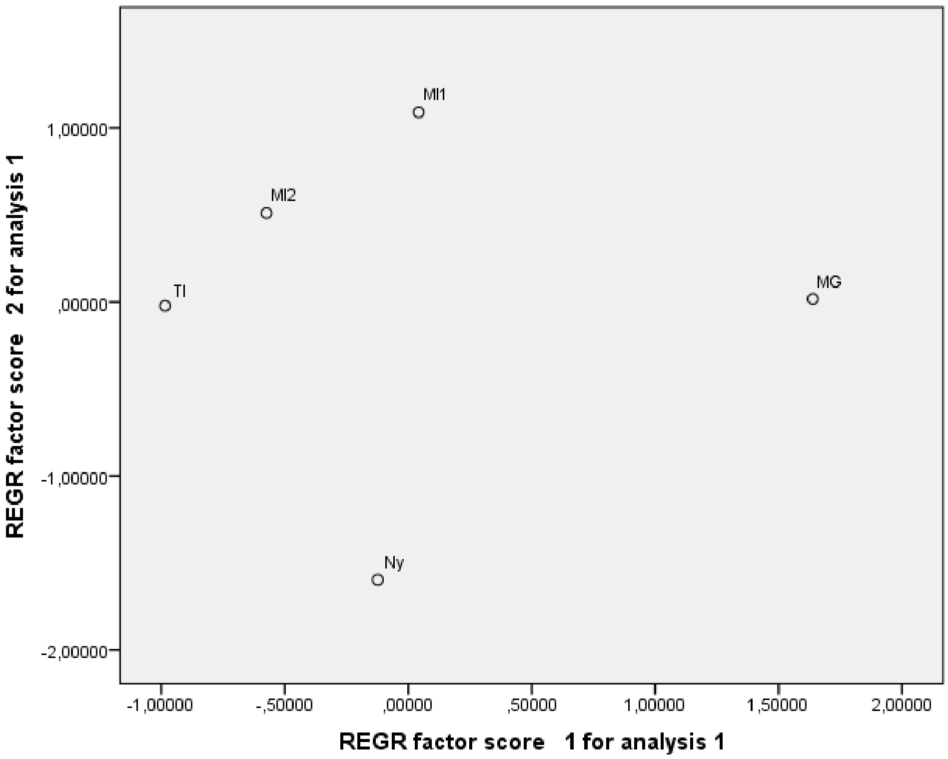


**Fig-4: Graphical representation of variables environments (On the factorial plane F1xF2 with 93.96% of explained Eigen Values)**

## Conclusion

The results, obtained in this study, indicated that the ten pearl millet genotypes performed significantly different. These results showed that there was genetic variability in the material studied. The environments played an important role in phenotypic expression of grain yield and yield components (number of tillers per plant, number of panicle and tillers eight). The correlation analysis of the study revealed that the number of tillers per plant, the number of panicle length and the tillers eight were important yield components. Among ten varieties the variety MI1054 showed the highest average grain yield (1.462 tons per ha) but the variety MI1363 showed the best stability across environments with 1.265 tons per ha of grain yield. The varieties GB8735 and H-80-10-GR showed high performance for the region of Magaria, when HKP is better for Niamey. The region of Magaria appears to the best region for pearl millet genotype test for grain yield.

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