Effects of long-term different fertilization on yield stability of maize

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Abstract
A long-term experiment was started in early 1990s and continued until 2008 to study the effects of crop rotation and chemical fertilization on the yield and yield stability of maize (*Zea mays L.*). The results indicated that the yield of maize was higher in the cropping system of soybean-maize rotation than that in maize monoculture. Under P combined with K fertilizer (PK) treatment and no fertilizer control (CK), the yield of maize increased in the crop rotation system up to 38.30% and 36.11%, respectively. This observation can be explained by residual nutrients after legumes, especially N nutrient. However, the rotation effect would be diminished by balanced nutrient supply. Maize yield increased significantly under N fertilization treatments and was even higher under the treatments of N combined with P (NP) and NP plus K (NPK). The stability analysis showed that stability of maize yield of soybean-maize rotation was significantly improved compared to maize monoculture, and higher stability could be obtained in NP and NPK treatments regardless of crop sequences, which can be attributed mainly to balanced macronutrients supply.

Key Words
Long-term trail, yield stability, crop rotation, drylang maize yield.

Introduction

The worldwide agricultural structure has been undergoing profound changes in recent decades, and one of the major changes is the utilization of chemical fertilizers to achieve high crop yield. The yield as well as the yield stability are the most important targets to evaluate a cropping system (Piepho 1998). The researches showed that the yield stability was significantly influenced by agricultural practices and the environment, especially fertilization, seed genotype, tillage, precipitation, accumulated temperatures, pests, and diseases (Berzsenyi and Dang 2008). The common approaches to stability analysis were environmental variance parameters, regression (Crossa 1990) and the fluctuation of production about a long-term average or the fluctuation of production about a long-term trend can be assessed by the long-term experiments. To some extent, long-term experiments are indispensable in investigations on the stability of crop production, predicting soil carrying capacity and assessing system sustainability (Regmi *et al.* 2002).
The objectives of this work were (i) to evaluate the long-term effects of different fertilization treatments and crop rotations on maize yield based on about 20 yr of data and (ii) to study the effects of fertilization treatments and rotations on yield stability by conventional variance parameter analysis, regression analysis, and AMMI analysis.

Methods

Experimental site, design and treatments
A long-term field experiment has been conducted since 1990 in the Institute of Applied Ecology, Chinese Academy of Sciences (41° 32′ N latitude, 123° 23′ E longitude). The mean annual temperature of 7.0-8.0 °C. Its annual precipitation is about 700 mm. The soil of the experimental field is Luvisols soil. The initial properties of the surface soil (0-20 cm depth) were as follows: pH 6.5, soil organic matter of 20.9 g/kg, total nitrogen of 1.13 g/kg, total P of 0.44 g/kg, total K of 16.4 g/kg, soil available P of 10.6 mg/kg, and available K of 88.0 mg/kg. The experiment had 8 treatments: no fertilizer (CK), N, P, K, NP, NK, PK, and NPK treatments. N, P, and K fertilizers were applied at the rates of 150, 25, and 60 kg/ha/year in the form of urea, double superphosphate, and potassium chloride, respectively. Each plot area was 162 m^2, with a buffer zone of 1.0 m. Initially, in 1990, the experiment was started with a soybean-maize-maize 3-year rotation. Then there were two crop sequences for maize per year that the forecrop was maize or soybean, respectively, namely maize monoculture and soybean-maize rotation. Each treatment consisted of 3 replications.

Data analysis
Maize grain yield data was subjected to analysis of variance (ANOVA) followed by Duncan's multiple range test for multiple comparisons of paired means of treatments.

Stability analysis

Stability analysis on the experimental treatments and effect of rotation was carried out using univariate (variance and regression parameters). Among the variance parameters, the ecovalence (W^2), the stability variance (σ^2) were calculated using the STABLE proposed by Kang and Magari (1995). The regression method of stability analysis was applied as described by Finlay and Wilkinson (1963). The regression model can be written as

$$y_{ij} = \mu_i + \beta_i u_j + d_{ij} \tag{1}$$

where μ_i is the mean (expected value), i.e. the systematic effect of the ith treatment; β_i is a regression coefficient corresponding to the ith treatment; u_j is an effect of the jth environment and dij is a random deviation from the regression line. Finlay and Wilkinson (1963) suggested that slopes with $b_i < 1.0$, where b_i is an estimate of β_i obtained by regression onto the environmental mean, indicated better adaptation to poor environments, whereas slopes with $b_i > 1.0$ were best used in superior environments. A cropping system with an estimate of $b_i = 1$ showed an average response to environmental conditions.

Results

Yield response

The effects of crop rotation and fertilization on the grain yield of maize over the years 1991-2008 are summarized in Table 1. Application of N fertilizer significantly increase maize yield over the other treatments, and comparison of treatments revealed that the average yields of maize under combined application of N with P or K were significantly higher than those in control and N, P or K alone. It can be also seen that the yield of maize in monoculture was always lower than in soybean-maize dicultrue except NPK treatment, especially without N fertilizer. The yield-increasing effect of crop rotation was greatest in the PK treatment, followed by the CK and P, with the poorest effect for the NPK.

Table 1. Effect of fertilization and rotation on grain maize yield (1991-2008).

Treatments	Yield response (t/ha)		Increase yield(t/ha)		Yield-increase rate (%)	
	Monoculture	Soybean-maize	Monoculture	Soybean-maize	Monoculture	Soybean-maize
CK	3.302Aa	4.494Ba	-	-	-	-
N	5.641Ab	5.866Abc	2.339	1.372	70.85	30.53
P	3.688Aa	4.849Bab	0.386	0.355	11.70	7.89
K	3.438Aa	4.493Ba	0.136	-0.001	4.12	-0.03
NP	6.569Abc	6.698Acd	3.268	2.203	98.96	49.02
NK	6.205Ab	6.529Acd	2.903	2.034	87.91	45.26
PK	3.678Aa	5.087Bab	0.377	0.593	11.40	13.19
NPK	7.482Ac	7.477Ad	4.180	2.983	126.60	66.36

Data followed by the same letter (lowercase for different treatment and uppercase for different rotation) do not differ significantly at the $P \leq 0.05$ level.

Stability analysis

On the whole, the treatments without N fertilizer differed markedly from the remaining treatments. In soybean-maize diculture the better adaptation to poor environments of CK compared to monoculture can be interpreted as the rotation effect. Since both slopes of control treatment was less than 1.0 (Table 2), yield was not responsive to a superior environment. The slopes of P, NP and NPK in soybean-maize rotation were greater than in monoculture. The highest yield in all environments was achieved in NPK treatment.

Table 2. Linear regression parameters of grain yield on the environmental mean in a long-term experiment.

Treatments	Intercept		Slope		R^2	
	Monoculture	Soybean-maize	Monoculture	Soybean-maize	Monoculture	Soybean-maize
CK	-1.456	-0.235	0.951	0.832	0.746***	0.767***
N	-0.320	-0.375	1.192	1.098	0.731***	0.794***
P	-0.529	-0.713	0.843	0.978	0.668***	0.816***
K	-1.095	-0.649	0.907	0.904	0.721***	0.837***
NP	2.348	0.701	0.844	1.055	0.598***	0.874***
NK	-0.389	-0.230	1.319	1.188	0.723***	0.852***
PK	-0.772	0.277	0.890	0.846	0.434**	0.790***
NPK	2.214	1.224	1.053	1.099	0.603***	0.800***

**Significant at $P \leq 0.01$; ***Significant at $P \leq 0.001$.

In the maize monoculture there was no difference in stability between CK and K, and the difference between CK and P under high-yield smaller than under low-yield conditions. In the soybean-maize diculture comparable with the monoculture the stability of treatments CK, P and K were similar and they also showed better adaptation to poor environment. Only the treatment N indicated a good adaptation in superior environments and its yield level was higher up to an environment mean of 5.0 t/ha and 5.7 t/ha, respectively in the monoculture and soybean-maize diculture. Yields with NP, NK and NPK treatments have improved markedly in all environments and their yield levels were higher than environment mean yield. The stability and yield of NPK was greatest in maize monoculture. However, NP and P treatments were more stable in soybean-maize rotation.

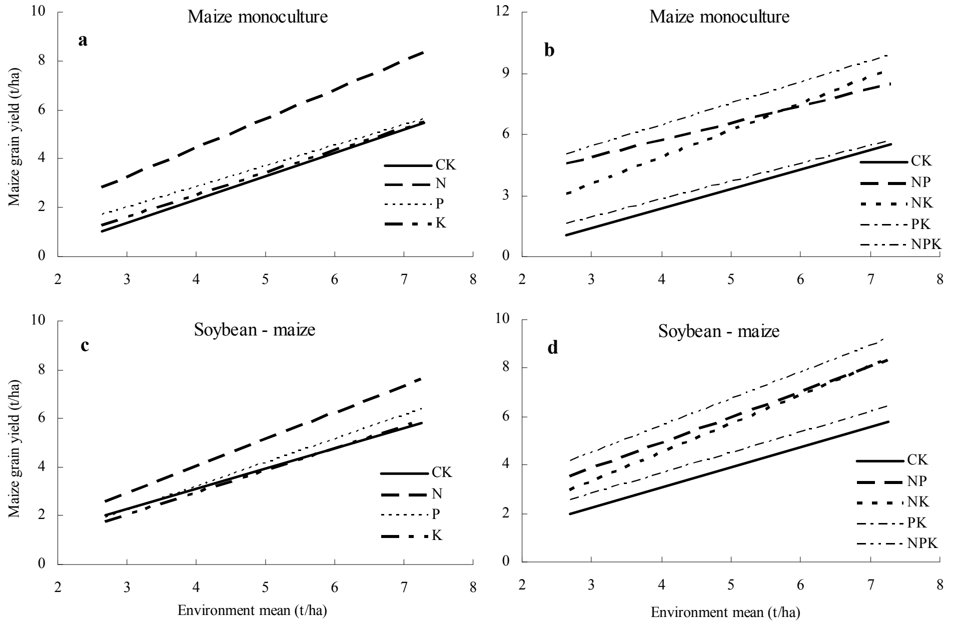

Figure 1. Stability of grain yield for different fertilization treatments according rotations vs. monoculture.

The CV % values, which evaluate the yield deviation, were the highest under PK treatment in monoculture system and under P treatment in crop rotation system. Because of the slight yield-increasing effect of P in superior environment, the yields fluctuation under P and PK were higher than in CK over the period of the experiment. The lowest CV % values were obtained under NP and NPK treatments. The CV values were practically higher in the maize monoculture than those in crop rotation. It suggested that the rotation effect can improve the stability of maize yield regardless of nutrients management. The stability variance index (σ^2) is the extent to which different treatments are responsible for the interaction. The values of stability variance index (σ^2) and ecovalence (W^2) were obtained under PK and P treatments and the smallest in NP and NPK treatments.

Table 3. Variance parameters of grain yield stability of maize (1991-2008).

Treatments	CV (%)		W^2		σ^2	
	Monoculture	Soybean-maize	Monoculture	Soybean-maize	Monoculture	Soybean-maize
CK	39.25	29.05	18.10	9.02	1.27	0.62
N	29.08	28.87	13.18	6.87	0.88	0.45
P	32.91	30.70	11.86	10.03	0.78	0.70
K	36.54	30.25	17.27	10.35	1.20	0.73
NP	19.56	23.16	7.31	5.42	0.42	0.34
NK	29.42	27.12	8.88	6.94	0.54	0.46
PK	43.21	25.72	24.60	7.66	1.78	0.51
NPK	21.33	22.61	7.70	5.24	0.45	0.32

Conclusions

Fertilizer N, P and K were used more efficiently in fully balanced than in imbalanced fertilizer treatments. The yield-stabilizing effect of crop rotation was mainly due to the residual soil fertility after soybean. Then the N-fixing effect of legume was also important for maize production. Under CK, PK, and single mineral fertilizer treatments, maize yield decreased and yield stability was poor. Balanced nutrient supply and appropriate cropping management practices were essential for the achievement of high yield and yield stability.

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