Proc. 17th Intern. Symp. of CIEC, 24-27 Nov. 2008 © NRC (Micronutrient Project), Cairo – Egypt, pp. 159-164 (2008)

ORGANICALLY FERTILIZED PLANTS CAN MANAGE WATER-LIMITED GROWTH CONDITIONS BETTER THAN MINERALLY FERTILIZED PLANTS. RESULTS FROM A MULTI-YEAR EXPERIMENT.

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Abstract :

Since 1980 a field trial is carried out on a sandy soil under dry-warm climate conditions (590 mm annual precipitation, 9.5°C annual mean air temperature) comparing farmyard manure with and without biodynamic preparations and mineral fertilizer, each treatment at three application rates between 60 and 140 kg total nitrogen per hectare. The amount of water available in June was a relevant yield determining factor ($p<0.05$) only for minerally fertilized wheat. During 13 years the manure fertilized wheat yielded between 30 and 50 dt ha^{-1}, irrespective to water availability. Manure fertilization gave lower maximum yields but higher minimum yields showing a better yield stability. With manure fertilization the wheat plants realized a better harvest index of 45% compared to mineral fertilization (41%; $p<0.05$). Other studies in this experiment revealed an enhanced root growth with better root distribution, even in the sub-soil, with manure fertilization and biodynamic preparations. This may have enabled the organically fertilized cropping system to compensate better for restricted growth conditions.

Introduction :

One of the most important cultivation factors influencing crop growth and yield certainly is fertilization. Basically, nutrients can be provided by organic or mineral fertilizers. It is still a matter of scientific discussion, whether the one strategy has advantages over the other (De Neve *et al.*, 2007), although several long-term field experiments in Europe and North America have proved a number of benefits of farmyard manure based organic farming systems for soil fertility parameters (Raupp *et al.*, 2006).

Apart from cultivation, plant development is governed by environmental conditions, mainly water availability. Water stress is considered to be one of the most important abiotic stress factors for crops (Asch, 2005). Models have been developed to predict yield formation under water stress during different growth stages (Cavero *et al.*, 2000). However, the interaction of cultivation and environmental factors under stress conditions is poorly investigated.

Therefore, the objective of our study is to evaluate yield development of spring wheat in a long-term field experiment with farmyard manure and mineral fertilizer application in respect of variable water supply in a period of years in order to find out, how either organically or minerally fertilized plants respond to drought.

Materials and Methods :

In 1980 a field trial was started to compare 3 different types of fertilizers, i.e composted farmyard manure (i) with and (ii) without application of all biodynamic preparations, and (iii) mineral fertilizers, at 3 application rates. All 9 treatments have been practised in 4 replicates, arranged in a split block design. Four identically structured fields were laid out, including all treatments and replicates, in order to cultivate 4 different crops each year. Plot size was 25 m^2. The experimental field was situated near Darmstadt, Germany (49E 50' N, 8E 34' E; 100 m a.s.l.). The soil was a Haplic Cambisol (87% sand, 8% silt, 5% clay in topsoil). The long-term averages of air temperature and precipitation were 9.5E C and 590 mm, respectively.

Since 1985 the experiment was continued with the same 9 treatments (3 by 3), but with a modified concept of application rate and another crop rotation. Now, the rates were based on the same amounts of total nitrogen applied with organic and mineral fertilizer in the respective treatment (Table 1). Whereas nitrogen amounts were fixed in each treatment, the phosphorus and potassium amounts applied with the manure treatments varied a bit from year to year depending upon manure composition. The values shown in Table 1 are averages of a number of years. The usual crop rotation included legume, mostly red clover (*Trifolium pratense* L.), spring wheat (*Triticum aestivum* L.), potatoes (*Solanum tuberosum* L.) and winter rye (*Secale cereale* L.). Except for fertilization, all other cultivation techniques were the same for all treatments and followed normal organic farming practises. Irrigation has been used in many years, but only in relatively small quantities of approx. 20 to 80 mm per year because of technical reasons. Further details of the experiment were published earlier (Raupp & Oltmanns, 2006).

Table 1: Treatments of the long-term fertilization experiment and nutrient amounts (kg ha^{-1}) applied yearly since 1985/86 with organic and mineral fertilizers to cereals

1st Factor: type of fertilizer					*Acronym*
composted cattle manure and urine					CM
composted cattle manure and urine with application of all biodynamic preparations					CMBD
mineral fertilizer (calcium ammonium nitrate, super phosphate, potassium chloride, since 1996 potassium magnesia)					MIN
2nd Factor: rate of fertilization (practised since 1985/86) to cereals					
N_t (kg ha^{-1})	P (kg ha^{-1})		K (kg ha^{-1})		
all types	MIN	CM/CMBD	MIN	CM/CMBD	
60	22	16	62	78	Low
100	33	22	83	138	Medium
140	44	29	104	196	High

For the present study, data from all treatments in 13 years between 1985 and 1999 were taken, when spring wheat yield has been evaluated. The wheat variety *Nandu* was cultivated in 1990-99, *Ralle* in 1985, 86 and 88, and *Star* in 1987. Data of straw yield were only available from 8 of these years (90, 91, 94, 95, 96, 97, 98, 99). For these years the harvest index was calculated as grain yield in percent of the total amount of grain and straw harvested from each plot. According to our usual marketing standards, the grain samples were cleaned after harvest, sieved for a minimum diameter of 2.2 mm and dried until 14% relative humidity. Therefore, broken and shrunk grain is not included in the yield results presented here. Data of air temperature, precipitation and irrigation have been monitored from the beginning of the experiment.

The data have been checked for normal distribution and processed by an analysis of variance (ANOVA) using the split block model of Federer (1975), example 7.3. This model represents the structure of our experiment exactly. Mean values were compared with a simple t-test. Values marked with different letters are statistically different ($p<0.05$). Linear regressions and correlation coefficients between yield and water supply were calculated and checked for significance ($p<0.05$) with the program PLABSTAT (H.F. Utz, Univ. Hohenheim).

Table 2: Grain yield of spring wheat (dt ha^{-1}) from different years after mineral fertilization (MIN), fertilization with farmyard manure without (CM) and with biodynamic preparations (CMBD), each at a low, medium and high rate; ANOVA results are shown for the main factors and interactions, LSD = least significant difference

	Low rate			Medium rate			High rate		
Year	MIN	CM	CMBD	MIN	CM	CMBD	MIN	CM	CMBD
85	44.2	42.9	44.4	43.6	48.1	46.2	39.7	45.8	43.5
86	30.0	26.9	25.7	31.4	30.6	32.2	33.0	32.6	31.0
87	49.2	37.6	35.5	56.1	36.2	36.3	55.4	44.6	38.6
88	29.8	28.7	32.1	27.3	30.0	34.1	26.5	30.3	34.9
90	26.9	31.9	36.1	27.1	33.5	35.3	29.2	34.5	34.3
91	36.6	40.3	37.0	33.4	46.1	41.9	34.0	49.8	45.4
92	40.1	31.8	34.7	43.2	32.7	36.2	45.3	38.2	37.4
94	29.7	31.9	34.9	34.6	34.3	34.1	37.3	37.4	36.9
95	37.4	33.3	34.1	38.9	39.5	40.0	38.1	42.0	44.2
96	42.3	46.6	45.3	44.2	48.5	49.8	45.1	50.1	49.7
97	37.3	39.2	37.0	37.4	42.2	38.9	37.1	41.1	39.4
98	44.2	33.7	37.2	47.6	40.9	41.4	45.8	45.7	45.2
99	45.3	33.2	33.8	50.0	40.8	39.7	49.4	44.6	46.0

ANOVA	F value	LSD ($p<0.05$)
YEAR	6.50 ($p<0.01$)	7.61
FERT. TYPE	0.07 (not sign.)	
FERT. RATE	24.95 ($p<0.01$)	1.10
TYPE x RATE	3.88 ($p<0.01$)	1.42
YEAR x TYPE	4.79 ($p<0.05$)	5.30
YEAR x RATE	0.43 (not sign.)	

Results and Discussion :

Fertilization effects on yield; the relationship between yield and water supply

Grain yield of spring wheat varied considerably over years and also between treatments (Table 2). The most pronounced influence on yield was analysed not for the type, but for the application rate of fertilizers ($F = 24.95$; $p<0.01$). No other factor or their interactions was of such importance for yield formation.

Apart from cultivation, environmental factors obviously had also a strong influence on yield. At the same application rate (medium, for example) in different years yields of 27 to 56 dt ha^{-1} occurred with mineral fertilization, and with the manure treatments 30-49 and 32-50 dt ha^{-1}, respectively. This indicates that site conditions, mainly wheather, may have had a marked influence on crop development. Considering the sandy soil and the dry-warm climate, water supply probably played an important role. To test this assumption, correlation coefficients were calculated between yield and water supply (sum of precipitation and irrigation) in single months during the vegetation period (data not shown). By this way, water supply in June revealed to have the most important influence on wheat yield.

However, water availability in this month did not show the same importance for all fertilizers. Yield of minerally fertilized wheat clearly increased with the amount of water supplied in June. This has been expressed by a significant linear regression of both parameters at each application rate (Fig. 1, left graphs). The F values of the regression were 3.88 ($p<0.10$), 7.49 ($p<0.01$) and 8.43 ($p<0.01$) at the low, medium and high rate, respectively. This finding is confirmed by the correlation coefficients showing a significant relationship only for the mineral treatments at least at the medium and high application rate, but not for all rates of both manure treatments (Table 3). The manure fertilized wheat achieved similar yields between 30 to 50 dt ha^{-1}, however, independent from water supply (Fig. 1, right graphs). The F values of the regression were 0.03, 0.82 and 0.39 (not significant). There was no difference between both manure treatments. That's why only the results of CM are presented.

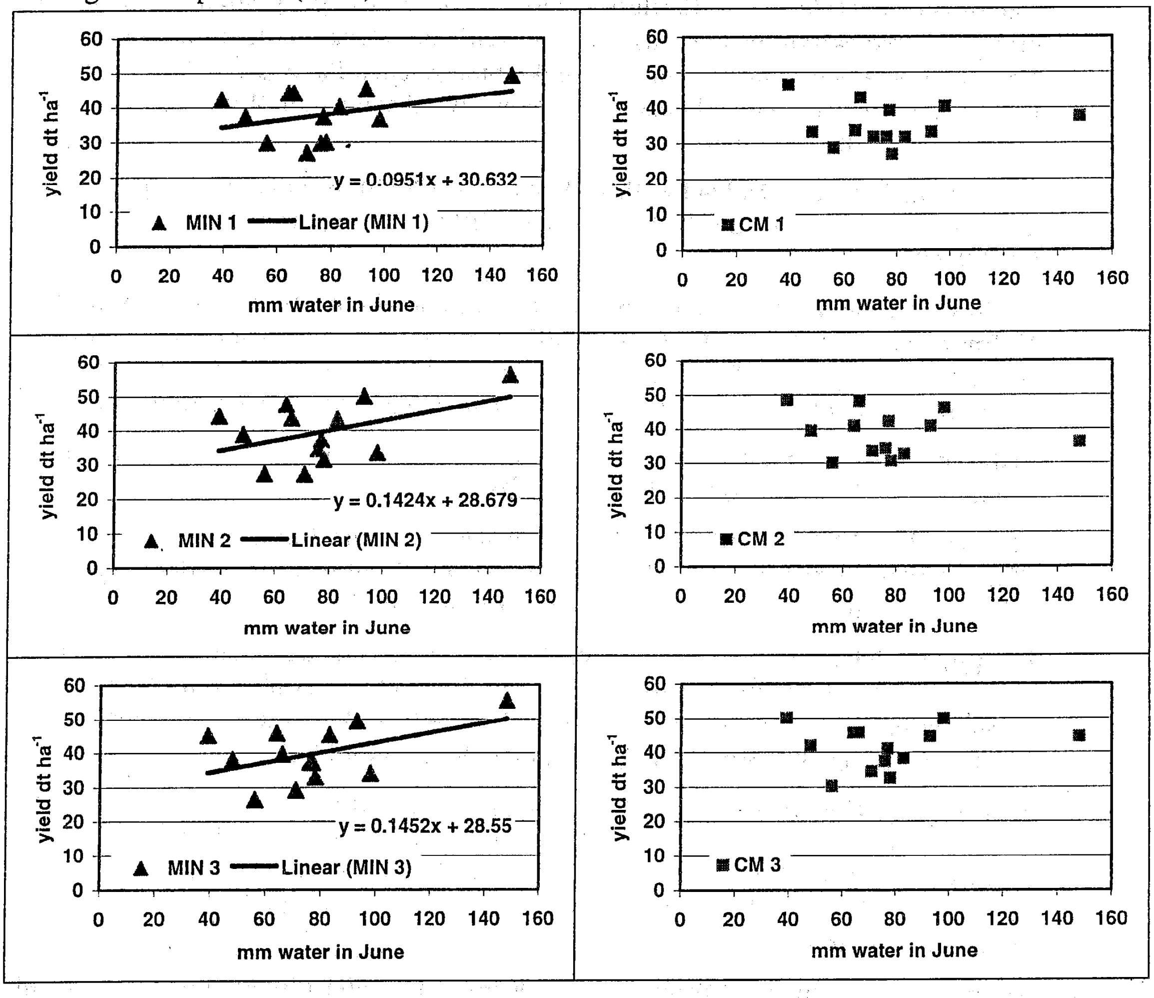
Table 3: Correlation coefficients *r* between wheat yields of different fertilization treatments and the amount of water supplied in June; based on yield data from 13 years and 4 replicates per treatment (n=52); ** means $p<0.01$

Fertilization	MIN	CM	CMBD
Low	0.268	-0.024	-0.161
Medium	0.361**	-0.127	-0.242
High	0.280**	0.088	-0.147

Another investigation over a period of 14 years of this experiment showed that manure fertilization gave a better yield stability. Compared to the mineral treatments manure fertilization gave lower maximum wheat yields but higher minimum yields (Raupp, 2001). Top yields under good growth conditions have been lower in the manure treatments. However, yield decline under poor growth conditions (in dry years) was smaller in the organic treatments.

It can be concluded from such findings that the organically fertilized plants are able to compensate better for dry growth conditions and are possibly more tolerant against water stress. A reason for this ability may be a more effective root system of the plants. A higher root length density of spring wheat (Meuser, 1989) and winter rye, even in the sub-soil (Bachinger, 1996), has been observed in the manure treatment with biodynamic preparations.

Fig. 1: Linear regression between wheat yields with mineral fertilization (MIN, left graphs) and with manure fertilization (CM, right graphs), each at 3 application rates (above, middle, below) and the amount of water supplied in June; yield data from 13 years, each treatment on average of 4 replicates (n=13)



Fertilization effects on harvest index

Organically fertilized plants transformed nutrients and environmental conditions more efficient into grain yield. The harvest index of the manure fertilized wheat plants (45.3%) was significantly higher than with mineral fertilization (41.0%), see Table 4. This means that under site conditions being limited with respect to water or nutrients a cropping system with manure fertilization has an advantage over a system based on mineral fertilization.

Table 4: Harvest Index (%) of spring wheat after mineral fertilization (MIN), fertilization with farmyard manure without (CM) and with biodynamic preparations (CMBD), each at a low, medium and high rate ($p<0.05$)

Fertilization	MIN	CM	CMBD	av.
Low	42.1	45.5	45.8	44.5 b
Medium	40.7	44.8	45.6	43.7 a
High	40.2	45.5	44.5	43.4 a
av.	41.0 a	45.3 b	45.3 b	

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