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Variability of soil water and nitrogen as causes of yield variability in heterogeneous fields

D. Geesing, R. Gutser and U. Schmidhalter
Technical University of Munich, Department of Plant Science, Chair of Plant Nutrition, Am Hochanger 2, Freising, D 85350, Germany, geesing@weihenstephan.de

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Abstract

Grain yield of winter wheat is influenced by water and nitrogen supply. To evaluate their relevance under varying plant available soil moisture (ASM), winter wheat was grown on two sites of different ASM with two nitrogen levels and three water levels. Yield on the site of low ASM was significantly influenced only by water supply, while on the site of high ASM the major cause of yield variability was the applied amount of N-fertiliser.

Introduction

The variability of soil nitrogen and of soil water are major causes of yield variability. Soil nitrogen largely depends on farm management, while soil water content is mainly the result of soil texture, topography and weather, which are little manageable factors. The objective of the present study is to investigate the magnitude of the importance of precipitation and N-fertiliser for winter wheat yield and quality on sites of different soil texture. Results may contribute to underline or, on the contrary, to reconsider the importance of soil texture maps for precision farming in pedologically and climatically heterogeneous areas such as southern Bavaria in Germany

Materials and methods

Soil texture of several fields in the foothills of the Alps was carefully mapped until a depth of 90 cm (considered as rooting zone). The resulting plant available soil moisture (ASM) was displayed as soil maps to support the selection of two experimental sites on one field where winter wheat was grown. For the site number one on sandy loam to loamy sand, the average ASM ranges between 110 - 120 mm/90 cm, for the second site on loam, silty loam and clayey loam, the average ASM ranges between 150 - 160 mm/90 cm.

On each site, plots of two different N-fertiliser treatments and three different soil moisture treatments were set up. Fertiliser was given at total rates of 120 kg of nitrogen/ha (applied at three different times at rates of 50/40/30 kg per ha) and 180 kg N/ha (50/70/60 kg per ha). One third of the plots in each site was covered by a transparent rain-shelter around 150 cm above ground, one third of the plots were trickle-irrigated receiving 100 mm in addition to rainwater within 3 weeks after beginning of shooting, and one third was left rain-fed as control plots. On each plot, volumetric soil moisture content was regularly monitored in soil depths ranging from 10 to 100 cm in 10 cm increments using a portable Diviner capacitance probe (Sentek Pty Ltd., South Australia). One irrigated, one control and one rain-sheltered plot of each site were additionally equipped with EnviroScan (Sentek Pty Ltd., South Australia) capacitive multisensor probes with sensors in 20 cm increments to a depth of 100 cm, which remained permanently in situ during the trial. Soil water suction at 20 cm, 60 cm and 100 cm were regularly measured by tensiometers on each plot.

At the end of the trial, each plot was separately harvested and plant material was analysed for N, P, K content in dry matter, for grain and straw yield, for ears per square meter and for different quality parameters such as 1000-grain-weight and grain diameter.

Results

Drought caused a decline in soil moisture content throughout the soil on the site of high ASM, but had little effect throughout the soil on the site of low ASM. Irrigation events were noticeable approximately down to 20 cm soil depth on the site of high ASM and down to 60 cm on the site of low ASM, on both sites apparently preventing lower layers from depletion while soil moisture throughout the soil of the control plots steadily declined. Neither water logging nor depletion beyond wilting point was found.

Chemical analyses of the grains showed for both sites higher grain nitrogen content for the rain-sheltered plots than for the control plots, the latter significantly more than the irrigated plots. Grain phosphorus content was also lowest for the irrigated plots. As for potassium, this order was reversed. The application of higher amounts of N-fertiliser resulted in higher grain nitrogen content but affected neither the potassium nor the phosphorus content of the grains. A first tentative estimation of grain quality could not clearly assign physical grain characteristics such as weight or diameter to differences in water supply or fertiliser level. Yet, a higher N-fertiliser level seemed to augment the portion of grains with bigger diameter for the site of low ASM, while on the site of high plant water availability a higher N-level resulted in greater 1000-grain-weight (Tab.1).

Table 1. Grain N,P,K contents (in % of dry matter) of winter wheat grown on plots under two N-fertiliser levels and three water treatments on sites of different ASM.

	low ASM	high ASM
N	S = 2.80 >> C = 2.34 >> I = 2.08	S = 2.60 >> C = 2.24 > I = 2.23
P	C = 0.42 > S = 0.42 >> I = 0.38	S = 0.39 > C = 0.38 > I = 0.375
K	I = 0.49 >> C = 0.46 >> S = 0.41	I = 0.48 >> C = 0.45 >> S = 0.41
quality *	S (>) C (>) I	(no)
N	N(180) = 2.56 >> N(120) = 2.31	N(180) = 2.499 >> N(120) = 2.23
P	N(180) = 0.41 = N(120) = 0.41	N(120) = 0.38 = N(180) = 0.38
K	N(120) = 0.45 = N(180) = 0.45	N(120) = 0.45 = N(180) = 0.45
quality *	N(180) (>) N(120)	N(180) (>) N(120)

S = rain-shelter; C = control; I = irrigation; ASM = available soil moisture; DM = dry matter (grain); N(180 or 120) = amount of N-fertiliser applied; >> = mean difference is significant at the 0.5 level; * only tentative estimation

On the site of low ASM, grain yield was highest for the irrigated plots, followed by the control and then by the rain-sheltered plots. On the site of high ASM, only the rain-sheltered plots showed significantly lower yields than the other treatments. Hundred mm water input from irrigation increased the average yield for both sites by 17 %, while drought decreased the yield by 32 % compared to the control. Results look different when both sites are looked at separately. The low ASM site showed 17 % higher yield due to irrigation when compared to the control, while yield declined by 46 % when drought-stressed. On the high ASM site, irrigation increased yield by 1 % and drought decreased yield by 12 % (Tab.2).

Table 2. Grain yield (dt ha^{-1}) of winter wheat grown on plots under three water treatments on sites of different ASM.

L+ H	I = 73.5 >> C = 62.6 >> S = 42.1
L	I = 71.1 >> C = 54.2 >> S = 29.4
H	I = 77.5 > C = 76.5 > S = 67.3

L = site of low ASM, H = site of high ASM, see also Tab. 1

A 40 mm/90 cm ASM increase resulted in a 46 % higher grain yield averaged for both sites. Comparing the two N-fertiliser levels, the difference is exacerbated (53 % at the 180 kg N/ha level versus 40 % at the 120 kg N/ha level) (Tab. 3).

Additional 60 kg N/ha increased the grain yield by 14 % on the site of high ASM but only by 4 % on the site of low ASM (Tab. 4).

Table 3. Influence of ASM on grain yield (dt ha^{-1}) of winter wheat grown under different N-fertiliser levels.

N(180+120)	ASM(H) = 73.8 >> ASM(L) = 50.2
N(180)	ASM(H) = 78.7 >> ASM(L) = 51.2
N(120)	ASM(H) = 68.8 >> ASM(L) = 49.2

see also Tab.1 and 2

Table 4. Grain yield (dt ha^{-1}) on sites of different ASM as influenced by N-fertiliser level.

ASM(H+L)	N(180) = 61.1 > N(120) = 56.3
ASM(H)	N(180) = 78.7 > N(120) = 68.8
ASM(L)	N(180) = 51.2 > N(120) = 49.2

see also Tab. 1 and 2

N-fertiliser showed different efficiency for site and external water supply. Differences between the two N-levels were largest when fertiliser was applied under drought on the site of high ASM but practically zero when drought-stress occurred on a low ASM site (Tab 5).

Table 5. Influence of N-fertiliser level and ASM on grain yield (dt ha^{-1}) under three different water treatments.

shelter	ASM(H) = 67.3 >> ASM(L) = 30.0
N(180)	ASM(H) = 73.6 >> ASM(L) = 29.3
N(120)	ASM(H) = 61.0 >> ASM(L) = 29.6
control	ASM(H) = 76.5 >> ASM(L) = 54.2
N(180)	ASM(H) = 81.8 >> ASM(L) = 55.6
N(120)	ASM(H) = 71.2 >> ASM(L) = 52.7
irrigation	ASM(H) = 77.5 > ASM(L) = 71.1
N(180)	ASM(H) = 80.8 >> ASM(L) = 73.0
N(120)	ASM(H) = 74.2 > ASM(L) = 69.2

see also Tab. 1 and 2

Discussion

The amount of N-fertiliser applied seems to affect grain yield on sites of low ASM to a much smaller extent than external water supply does and consequently, precipitation may here be considered of utmost importance. The higher plant available soil moisture becomes, the more the importance of the applied amount of N-fertiliser increases. For both types of ASM but for different reasons, the findings suggest that there is a need to reconsider the role of soil texture mapping.

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