# IMPORTANCE OF SPATIAL AND TEMPORAL SOIL WATER VARIABILITY FOR NITROGEN MANAGEMENT DECISIONS

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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 applying 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-fertilizer.

## 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 not manageable factors.

Soil maps and soil models are therefore often considered as unavoidable for operational site-specific farming. Soil mapping by field sampling is, however, labour-intensive and the meaningfulness temporally and locally limited. Soil moisture sensors, on the other hand, allow rapid and physically less strenuous inspection of larger areas. The quality of sensor data, however, is kept within limits set by other soil parameters and the purchase of sensors is often cost-prohibitive. Further, the ensuing processing of the acquired field data require geostatistical assumptions or models which reduce its usefulness only to experts.

If site-specific management strategies can be developed that are merely based on empirical data acquisition such as management, precipitation and temperature patterns on one side and output (yield and quality of the crop) on the other side - and thus considering the soil as a blackbox - it would certainly avoid or reduce tedious and costly soil mapping to a minimum.

The objective of the present study is to investigate the magnitude of the importance of precipitation and N-fertilizer 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 to a depth of 90 cm (considered as rooting zone). For each sampling point plant available water was calculated according to the guidelines of the German Soil Society (AG Boden, 1996). Results were displayed as soil maps to support the selection of two experimental sites on one field where winter wheat was grown. For site number one on sandy loam to loamy sand, the average plant available soil moisture (ASM) ranges between 110 - 120 mm 90 $cm^{-1}$, for the second site on loam, silty loam and clayey loam, the average ASM ranges between 150 - 160 mm 90 $cm^{-1}$.

On each site, plots of two different N - fertilizer treatments and three different soil moisture treatments were set up. Fertilizer was given at total rates of 120 kg of nitrogen ha$^{-1}$ (applied at three different times at rates of 50/40/30 kg ha$^{-1}$) and 180 kg N ha$^{-1}$ (50/70/60 kg ha$^{-1}$). One third of the plots of 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. A completely randomized two-factorial design was set up on the site of low ASM while - due to technical restrictions - a split-splot design was established on the site of high ASM with N rates as main plots and water supply as subplots.

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). The probe was lowered into PVC access tubes that were inserted into hand augered holes. The capacitance probe method measures the soil-water-air mixture and the water content at different electromagnetic field frequencies. The frequency collected by the instrument was converted into percent volumetric water content using the default calibration equation of Sentek Pty Ltd.. One irrigated, one control and one rain-sheltered plot of each site were additionally equipped with EnviroScan capacitive multisensor probes with sensors in 20 cm increments to a depth of 100 cm which remained permanently in situ during the trial. These sensors were hourly logged.

Soil water suction at 20 cm, 60 cm and 100 cm were regularly measured by tensiometers on each plot. These instruments consist of a water filled tube with a porous ceramic cup on one end and sealed by a silicon stopper on the other end. Water suction was measured by piercing a hypodermic needle, itself connected to a pressure transducer, through the silicon stopper.

At the end of the trial, each plot was separately harvested and plant material was analyzed 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. Statistical analyses was performed by use of a general linear model with SAS software. The LSD-test was used for the comparison of mean values.

## RESULTS

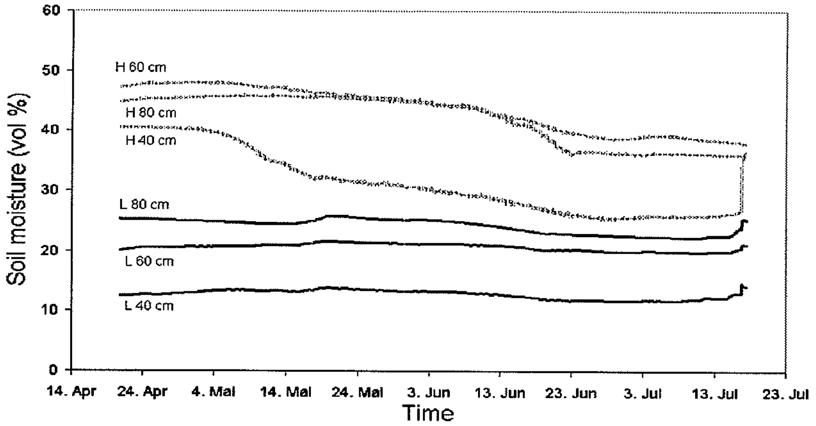

FIGURE 1 Soil moisture monitoring on rain-sheltered plots with different available soil moisture; H = high ASM, L= low ASM

ASM was between about 40 % for the upper 20 - 40 cm and 50 % in the soil lower than 60 cm, and between 15 to 35 % for the site of low ASM. Drought caused a permanent 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 (Figure 1). 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 apparently preventing lower layers, on both sites, from depletion (Figure 2) while soil moisture throughout the soil of the control plots steadily declined. For any The permanenty logged plots showed differences in soil moisture during the trial as to both range and course. At the beginning of the trial volumetric soil water content of the site of high

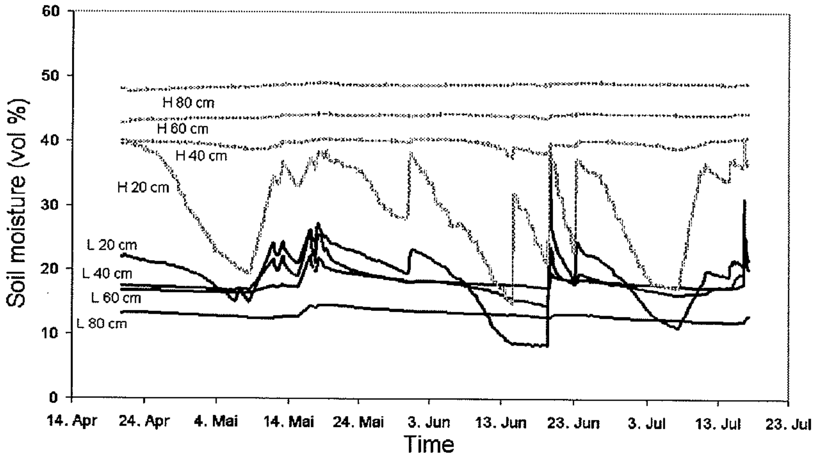

FIGURE 2 Soil moisture monitoring on irrigated plots with different available soil moisture; H = high ASM L = low ASM

permanently logged plot, neither water logging and, except for the first 20 cm under shelter on the site of low ASM, nor depletion beyond wilting point was found. The findings justify to attach more importance to the time pattern of precipitation for soils of coarse texture.

Chemical analyses of the grains showed significantly ($\alpha < 0.05$) higher grain nitrogen content for the rain-sheltered plots than for the control plots, the latter significantly more than the irrigated plots. A decrease in grain nitrogen content with increasing water supply occurred on both sites, i.e. the site of low plant available soil moisture (ASM) and the site of high ASM. Grain phosphorus content was also lowest for the irrigated plots, significantly, however only for the site of low ASM. As for potassium, the order was reversed and grains show, for both sites, a significantly higher grain potassium content on irrigated plots than on control plots, the latter more than on the rain-sheltered plots. (Table 1).The application of higher amounts of N-fertilizer resulted in a higher grain nitrogen content but affected neither the potassium nor the phosphorus content of the grains (Table 1).

No difference could be detected between the two sites of ASM as for grain nitrogen and grain potassium content, whereas grain phosphorus content was higher for the site of low ASM.

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 fertilizer level. Yet, a higher N-fertilizer 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 availibility a higher N-level resulted in greater 1000-grain-weight (Table 1).

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. The differences were significant. 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. Again, 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 % (Table 2).

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

| | low *ASM* | high *ASM* |
|---|---|---|
| *N % of DM (±SD)** | S = 2.807 (±0.175)a | S = 2.606 (±0.190)a |
| | C = 2.342 (±0.185)b | C = 2.247 (±0,125)b |
| | I = 2.080 (±0.239)c | I = 2.234 (±0.176)b |
| *P % of DM (±SD)* | C = 0.425 (±0.017)a | S = 0.390 (±0.016)a |
| | S = 0.419 (±0.024)a | C = 0.378 (±0.006)a |
| | I = 0.380 (±0.024)b | I = 0.375 (±0.010)a |
| *K % of DM (±SD)* | I = 0.488 (±0.018)a | I = 0.476 (±0.008) a |
| | C = 0.463 (±0.014)b | C = 0.452 (±0.007) b |
| | S = 0.409 (±0.030)c | S = 0.413 (±0.006) c |
| *quality ** | S (>) C (>) I | (no) |
| *N % of DM (±SD)* | N(180) = 2.561 (±0,334)a | N(180) = 2.499 (±0.206)a |
| | N(120) = 2.307 (±0.356)b | N(120) = 2.226 (±0.184)b |
| *P % of DM (±SD)* | N(180) = 0.409 (±0.029)a | N(120) = 0.382 (±0.012)a |
| | N(120) = 0.408 (±0.030)a | N(180) = 0.381 (±0.014)a |
| *K % of DM (±SD)* | N(120) = 0.454 (±0.034)a | N(120) = 0.449 (±0.030)a |
| | N(180) = 0.448 (±0.046)a | N(180) = 0.446 (±0.026)a |
| *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-fertilizer applied; SD=standard deviation;

* values followed by different letters are significantly different at $P=0.05$

** only tentative estimation

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 = 73.50 (±6,77)a | C = 62.56 (±13.79)b | S = 42.06 (±20.90)c |
| L | I = 71.10 (±5.90)a | C = 54.17 (±7.95)b | S = 29.43 (±6.98)c |
| H | I = 77.49 (±6.67)a | C = 76.54 (±9.07)a | S = 67.29 (±12.76)a |

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

Comparing the two N-fertilizer levels, the difference is exacerbated ( 53 % at the 180 kg N/ha level versus 40 % at the 120 kg N/ha level) (Table 3).

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

| | | |
|---|---|---|
| N(180+120) | ASM(H) = 73.77 (±10.37)a | ASM(L) = 50.19 (±18.93)b |
| N(180) | ASM(H) = 78.72 (±5.79)a | ASM(L) = 51.16 (±19.99)b |
| N(120) | ASM(H) = 68.83 (±11.84)a | ASM(L) = 49.22 (±18.42)b |

see also Table1 and 2

Additional 60 kg N/ha increased the grain yield, when both sites were pooled, by 9 %. Considering the sites separately, the same amount of nitrogen augmented the grain yield by 14 % on the site of high SAM but only by 4 % on the site of low ASM (Table 4). Differences are, however, not significant due to a high standard deviation.

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

| | | |
|---|---|---|
| ASM(H+L) | N(180) = 61.08 (±21.05)a | N(120) = 56.28 (±18.74)a |
| ASM(H) | N(180) = 78.72 (±5.79)a | N(120) = 68.83 (±11.84)a |
| ASM(L) | N(180) = 51.16 (±19.99)a | N(120) = 49.22 (±18.42)a |

see also Table 1 and 2

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

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

| | | |
|---|---|---|
| **shelter** | ASM(H) = 67.29 (±12.76)a | ASM(L) = 29.98 (±6.98)b |
| **N(180)** | ASM(H) = 73.56 (±5.64)a | ASM(L) = 29.25 (±6.50)b |
| **N(120)** | ASM(H) = 61.02 (±16.02)a | ASM(L) = 29.62 (±8.06)b |
| **control** | ASM(H) = 76.54 (±9.07)a | ASM(L) = 54.17 (±7.95)b |
| **N(180)** | ASM(H) = 81.83 (±5.09)a | ASM(L) = 55.61 (±9.64)b |
| **N(120)** | ASM(H) = 71.24 (±9.31)a | ASM(L) = 52.74 (±6.64)b |
| **irrigation** | ASM(H) = 77.49 (±6.67)a | ASM(L) = 71.10 (±5.90)a |
| **N(180)** | ASM(H) = 80.76 (±2.60)a | ASM(L) = 72.99 (±3.58)b |
| **N(120)** | ASM(H) = 74.23 (±8.51)a | ASM(L) = 69.21 (±7.52)a |

Table 5 see also Table 1 and 2

Attention should be drawn to the the observation that, when irrigated (or under years of high precipitation), the gap between low and high yield diminishes.

## CONCLUSIONS

The amount of N-fertilizer 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 larger plant available soil moisture becomes, the more the importance of the applied amount of N-fertilizer increases. For both types of ASM but for different reasons, the findings suggest to reconsider the role of soil texture mapping.

## REFERENCE

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