Opportunities and Challenges of a Real-Time Control of Seeding Depth

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A variation of seeding depth did not play any role in agricultural application. Modern spacing drills offer the possibility for a mechanical change of the seeding depth but it is scarcely used as the user does not know on what the setting should rely on. Changing soils and topographic variations are responsible for different water contents in the top soil layer. A simulation model for corn is supposed to include spatial viability. Through variation of seeding depth it allows to establish uniform conditions for germination.

Keywords

Site specific seeding, real-time, numeric models, simulation, precision farming

Introduction

Germination and emergence is an important process in growing vegetable products. For a quit and consistent germination a sufficient amount of water, oxygen and heat must be available for seeds. Soil and it's physical properties play a decisive role for the prevail germination conditions.

Therefore soil temperature, matrix potential, seeding depth and oxygen supply influencing time for germination and emergence had been investigated in many laboratory and field trials yet[13; 16]. A common conclusion of the laboratory trials is that optimum temperatures, free water availability and a shallow seeding depth guarantee a quick emergence.

But outdoor conditions are essentially complex. The inverse vertical gradients of soil temperature and soil moisture [1] make optimum temperatures and free water availability impossible.

Soils, where germination takes place, are part of a complex system consisting of soil physical properties, weather and relief (**figure 1**). Different germination conditions depending on time and place conclude from that. Therefore it is not possible to state guide numbers for seeding depths. Up to now corn is seeded in dependence of the kind of soil in four centimetre on heavy and six centimetres on light soils[9; 20].

Germination determining factors

Temperature has a major influence on the germination duration of corn [16]. As temperature raise the imbibition rate of the seeds also increase, not depending of the soil matrix potential [12]. Corn needs a sufficient temperature supply because of the physiological minimum temperature of 10 °C. At low soil temperatures the growth of the coleoptile ceases and the first leafs break through the coleoptile below soil level. The shoot growth was disoriented [14] and about 15 % of the nonemerged seedlings showed this abnormal shoot morphology in a field experiment. Low temperature at night is responsible for this malformation [5] and Ullstrup [18] found there is no evidence that pathogens are involved.

Cool and humid conditions impede the corn development but the moist environment is favourable for fungi pathogens. This results in reduced seedling emergence and fungi infection.

After temperature soil moisture has the greatest effect on germination as germination only after water imbibition occurs. The imbibition rate of the seed depends on the matrix potential of the soil, the hydraulic conductivity of seed and soil as well as the contact area between soil and seed [16]. Imbibition is the effect of balancing the soil and seed water potential which requires a minimum of hydraulic conductivity of the soil [10]. In a drying soil the water moistened contact area between seed and soil is decreasing. Therefore there is less cross sectional area for water movement through the soil toward to germinating seeds which results in a reduced hydraulic conductivity [8].

It's easy to transport enough water necessary for germination in a wet soil. But in a dry soil water movement is too less for germination [7]. Water potential in soil and seed become even and therefore the missing gradient is responsible that the water adaptation of soil and seed become zero.

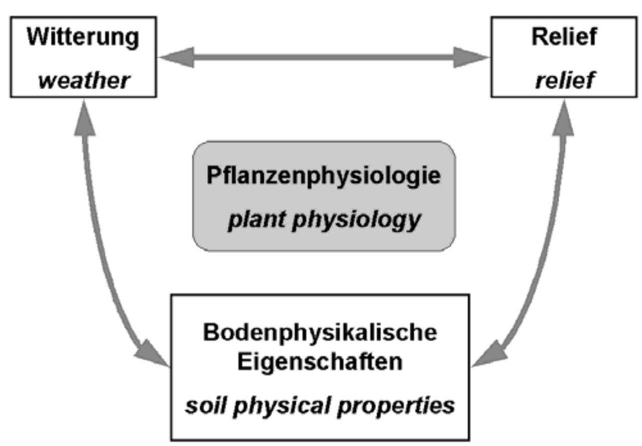

Figure 1: Germination determing factors in a soil

Opportunities of soil physical and plant physiological models

The determination of the best seeding depth requires the consideration of spatial variability and plant physiological properties. Meanwhile it's possible to satisfactory describe those factors in mathematical models:

- Darcy's law and the Richards equation [15] allow to describe temperature and soil moisture in dependence of time and place. Soil physical properties and weather data (air temperature, precipitation, irradiation, relative humidity and wind speed) need to be available. The water retention curve of the soil which is a fundamental factor in simulation models can be predicted by the kind of soil, texture, bulk density and organic matter [19].
- Digital elevation models (DEG) consist of three-dimensional coordinates, descriptions of the data structure and algorithms and they allow the projection of the terrain on a computer. With a geographic information system (GIS) it is possible to calculate different indices and spatial processes, that run on the soil surface or the top soil layer can be interpreted. For example Sinai et al. [17] investigated the effect of curvature on soil moisture on a 0.5 ha area with common land use and found high correlation coefficient (r = 0.81). Burt & Butcher [6] also found high correlations with the soil moisture for the relief parameters horizontal curvature, specific catchment area and wetness index [2]. The highest correlation were between soil moisture and the mathematical product of horizontal curvature and wetness index and was found on a slope area of 1.4 ha.

Those models allow the spatial and time determination of soil temperature and the matrix potential and therefore the most important germination factors. In a field trial in April 2000 measured and calculated temperatures and soil moisture contents were compared. **Figure 2** shows the temperature values in depths of four and six centimetres. A correlation coefficient of r = 0,96 was found. Temperature and moisture courses calculated in this way build the basis of plant physiological models that enable the description of germination and

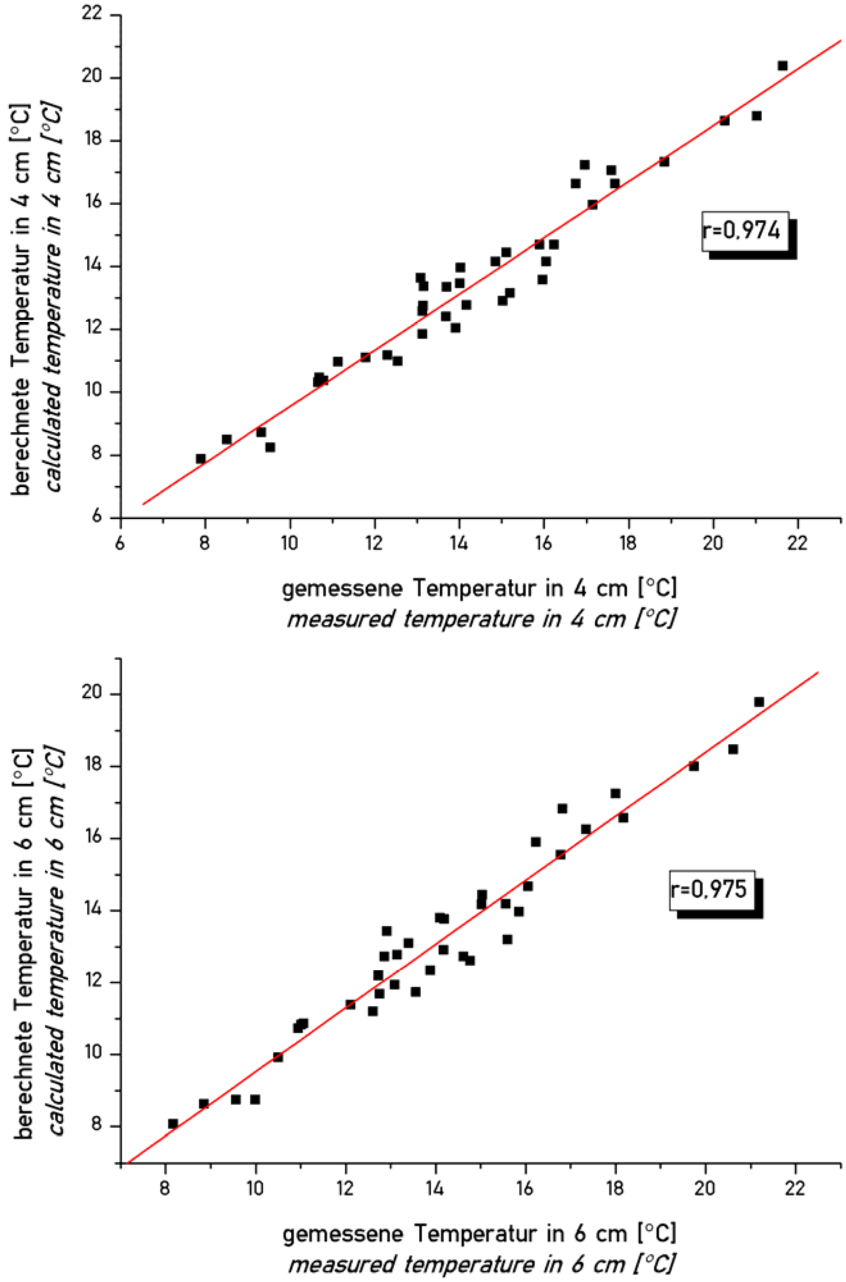

Figure 2: Calculated and measured soil temperature values in a depth of 4 cm (above) and 6 cm (below)

emergence processes:

- Blacklow [3] found a model based on water imbibition of the seed and root and shoot grow that calculates the emergence time of corn in dependence of temperature amplitudes. He estimates the change in water content with the hourly change of temperature and guess the time of germination by the total seed water content. His model shows the big influence of temperature on the time of germination. Even a temperature difference of 1 to 2 °C result in a delayed emergence time of 28 hours. The model only considers the temperature as a variable but not the soil moisture content. The calculated germination and emergence duration satisfactory fit to the measured laboratory values and field trials.
- Bradford [4] brings temperature and matrix potential in line in his Hydrothermal-time model. Therefore the model of heat sums which is used to describe different states of development of the plant is extended by the matrix potential (equation 1; T = temperature [°C], Ψ = matrix potential [Mpa], t = time [d]). Base temperature T_b (corn: 10 °C) and base ma-

trix potential Ψ_b (corn: -2,89 MPa). are the fundamental factors of the model. Both values are the lower physiological limit below no germination can occur. All temperature and matrix potential values that are higher than the base values are contributed in the model. The higher the temperature and the smaller the matrix potential the faster germination will occur. Corn germinates when a value of $\theta_{HT} = 88{,}8$ MPa °Cd is achieved.

$$\theta_{HT} = (\psi - \psi_b) \bullet (T - T_b) \bullet t \qquad (1)$$

Weather as unknown quantity

The described models allow a satisfactory description of the germination and emergence duration but on condition that the weather conditions are known. For detecting a favourable seeding depth it is necessary to calculate germination and emergence duration before sowing and therefore the future weather conditions must be estimated. Stochastic weather models can be approached to generate conceivable weather data based on history weather conditions. On the other hand historic weather conditions can be directly used for calculation.

In 2004 both methods did not produce the expected results. Wet and cool weather provided suboptimal germination conditions and therefore for extended germination and emergence durations. Germination delaying weather conditions like drought and cold can’t be predicted in advance. It’s best to use average weather data determine a favourable seeding depth. An advantage of stochastic weather models is that they consider dry and wet days with their corresponding likelihood that they set in. But if historic weather data is use to calculate the arithmetic mean rainfall would occur every day with 3 to 5 l/m² which is not equivalent to real weather conditions.

Real time control of seeding depth

A real time control of seeding depth requires more than the simulation of soil physical and plant physiological processes. The current temperature and moisture conditions in the field play an important role. Therefore the current soil temperature and soil moisture needs to be measured while crossing the field [11]. The site properties and the models mentioned before allow to predict future temperature and moisture conditions and with that possible germination and emergence durations. But the present computer power precludes an online execution of all calculation steps on the drill with a satisfying spatial resolution. To ensure a quick control of the seeding depth it is practical to use a multi-stage procedure. First temperature and moisture conditions as well as germination and emergence durations are simulated for different surroundings and saved into an array. During seeding the seeding depths are then retrieved from a database in dependence of the position, soil temperature and soil moisture and adjusted on the drill unit (**figure 3**).

Outlook

The online variation of seeding depth complements precision farming with another procedure. Field trials on different locations will now show whether this new procedure provides faster emergence and a homogeneous crop. This might reduce the weed pressure and therefore the application rates of herbicides. Another positive effect is the reduction of soil erosion because of the fast soil coverage as well as a process improvement in no-till farming. It also improves dryland farming as a moisture depending seeding procedure cost and energy intensive irrigation might become unnecessary. A homogeneous crop could also lead to higher yields.

References

[1] *Akpaetok, O.I.:* Zur Sorptionsgenetik des Bodenwassers beim keimenden Saatgut., 1980.

[2] *Beven, K.J. U. M.J. Kirkby*: A Physically Based, Variable Contributing Are Model of Basin Hydrology. Hydrological Sciences 24 (1979), S. 43-69.

[3] *Blacklow, W.M.:* Simulation Model to Predict Germination and Emergence of Corn in an Environment of Changing Temperature. Crop Science 13 (1973) Nr. 6, S. 604-608.

[4] *Bradford, K.J.:* Water Relations in Seed Germination. In: Seed Development and Germination. Hrsg.: Kigel, J. u. G. Galili, Marcel Dekker, Inc., New York, 1995, S. 351-396.

[5] *Buckle, J.A. U. P.M. Grant:* Effects of Soil Temperature on Plumule Growth and Seedling Emergence of Maize. The Rhodesian Journal of Agricultural Research 12 (1974), S. 149-161.

[6] *Burt, T.P. U. D.P. Butcher*: Topographic Controls of Soil Moisture Distributions. The Journal of Soil Science 36 (1985), S. 469-486.

[7] *Dasberg, S.:* Soil Water Movement to Germinating Seeds. Journal of Experimental Botany 22 (1971), S. 999-1008.

[8] *Ehlers, W.:* Keimung in Abhängigkeit von bodenphysikalischen Prozessen. Kali Briefe 15 (1980), S. 233-248.

[9] *Entrup, N.L. U. J. Oehmichen*: Lehrbuch des Pflanzenbaus. Nr. 2: Kulturpflanzen. Th. Mann, Gelsenkirchen, 2000.

[10] *Hadas, A. U. E. Stibbe*: A Analysis of Soil Water Movement towards Seedlings

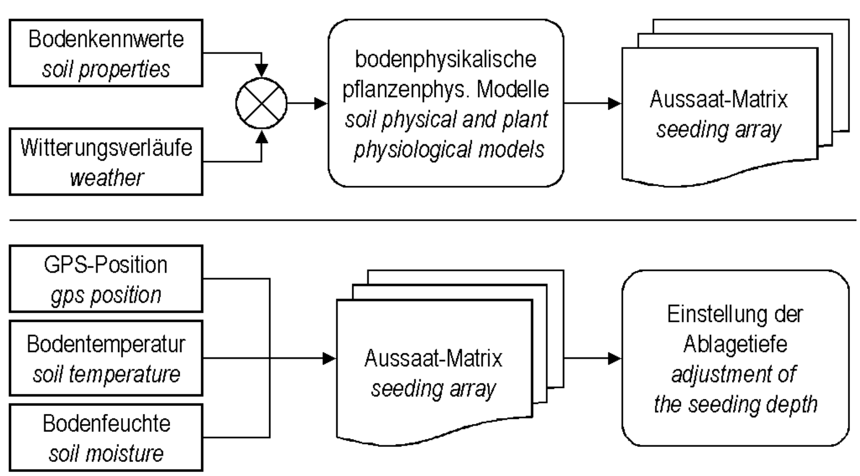

Figure 3: Multi-stage procedure for real-time control of seeding depth

Prior to Emergence. In: Physical Aspects of Soil Water and Salts in Ecosystems. Hrsg.: Hadas, A., D. Swartzendruber, P.E. Rijtema, M. Fuchs u. B. Yaron, Springer-Verlag, Berlin Heidelberg New York, 1973, S. 97-106.

[11] *Jantschke, C. U. K. Köller*: Bodenfeuchte Ermittlung in Echtzeit. Tagung Landtechnik 2004, VDI-Berichte Nr. 1855, Hrsg.: VDI-Max-Eyth-Gesellschaft, VDI Verlag GmbH, 2004, S. 435-440.

[12] *Lafond, G.P. U. B.D. Fowler*: Soil Temperature and Water Content, Seedling Depth, and Simulated Rainfall Effects on Winter Wheat Emergence. Agronomy Journal 81 (1989), S. 609-614.

[13] *Lindstrom, M.J., R.I. Papendick U. F.E. Koehler*: A Model to Predict Winter Wheat Emegence as Affected by Soil Temperature, Water Potential, and Depth of Planting. Agronomy Journal 68 (1976), S. 137-141.

[14] *Miedema, P.*: The Effects of Low Temperature on Zea Mays. Advances in Agronomy 35 (1982), S. 93-128.

[15] *Richards, L.A.*: Capillary Conduction of Liquids Through Porous Media. Physics 1 (1931), S. 318-333.

[16] *Schneider, E.C. U. S.C. Gupta*: Corn Emergence as Influenced by Soil Temperature, Matric Potential, and Aggregate Size Distribution. Soil Science Society of America Journal 49 (1985), S. 415-422.

[17] *Simunek, J., K. Huang U. M.Th. Van Genuchten*: The HYDRUS Code for Simulating the One-Dimensional Movement of Water, Heat, and Multiple Solutes in Variably-Saturated Media. Version 6.0. Research Report No. 144. Salinity Laboratory, USDA, ARS, Riverside, 1998.

[18] *Sinai, G., D. Zaslavsky U. P. Golany*: The Effect of Soil Surface Curvature on Moisture and Yield. Soil Science 132 (1981) Nr. 5, S. 367-375.

[19] *Ullstrup, A.J.*: Diseases of corn. In: Corn and Corn Improvement. Hrsg.: Sprague, G.F., American Society of Agronomy, Madison, 1977, S. 391-500.

[20] *Van Genuchten, M.Th.*: A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils. Soil Science Society of America Journal 44 (1980), S. 892-898.

[21] *Zscheischler, J.*: Handbuch Mais. DLG-Verlags-GmbH, Frankfurt am Main, 1990.

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