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Modelling the seedbed physical environment in relation to crop emergence.

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Final Technical Report on:

Modelling the seedbed physical environment in relation to crop emergence

NRSP Project No: EMC X0237 **Date:** 14 /8/96

Executive Summary

Poor or failed crop emergence is commonplace in the Semi-Arid Tropics (SAT) and is a major factor limiting crop yields for small farmers. The exact reasons for poor emergence are often not known. In order to provide solutions it is necessary to understand the reasons for poor emergence and the effects of possible intervention strategies on seedbeds and seedlings. This project set out to study these questions by developing a model of seedbed physical conditions and seedling growth in response to these conditions. Laboratory and field data were used to construct and provide parameters for the model (EMERGE). This was then tested against rates of emergence recorded during realistic sowing trials in the field in Tanzania.

The work showed that physical conditions in seedbeds (temperature, dryness and soil strength) could all cause failed emergence individually, or more commonly, in combination. The various parts of the model were validated individually and showed good agreement with field results. Limitations to the applicability of the present model components have also been identified and discussed. Model predictions showed that simple intervention strategies (eg. changing sowing date or sowing depth) could have profound effects on percentage seedling emergence. The results suggest that the model developed in this project could be used to assist in planning future practical field research on crop establishment, and that an extension of this approach could be used to develop a full crop establishment model to help educate and advise farmers in the Semi-Arid Tropics.

Background

Poor emergence is recognised as a serious problem in the Semi-Arid Tropics. A farmer's survey and research station estimates in Botswana report that 40% of crops need to be resown (Harris, *pers comm*). Even when resowing is not necessary, emergence is often erratic, leading to patchy crops and consequent loss of yield. Previous work at Hombolo in Tanzania had demonstrated the link between emergence and yield, and the impact that improved seedbed management could have.

The exact reasons for poor emergence, when it occurs, are usually not known although there are many documented cases in the literature of poor emergence due to specific causes set up by the experiments. From these is was possible to deduce that, for soils of the SAT, high temperatures, lack of water, and mechanical strength of soils could all lead to poor emergence either individually or in combination. Other factors such as predation or infection by pathogens may also be important but these have been excluded from our experiments by use of physical barriers, insecticides and fungicides. In order to suggest ways of getting more reliable emergence it is necessary (a) to understand the actual reasons for poor emergence where this occurs, and (b) to be able to predict the effects of any intervention strategies (e.g. mulching, changing sowing date, changing sowing depth, or seed priming) on seedling growth, given that temperatures, matric potentials and mechanical impedances experienced by the seedlings are all likely to be affected by any particular change in sowing regime.

Project purpose

It was decided that a modelling approach was the only way to achieve (a) and (b) above. The project therefore set out (i) to develop a general purpose emergence model, (ii) to provide parameters for two soil types of the Semi-Arid Tropics and (in conjunction with EMC X0213) growth of sorghum (var tegemeo) under varying physical conditions, and (iii) to test the model against field data collected in Tanzania.

Specific objectives of the project were:
i) To develop a model of water, temperature and strength regimes in seedbeds and to validate this in field experiments including studying intervention strategies such as mulching.
ii) To develop methods for generating synthetic hourly meteorological data required to run the model from daily or weekly means.

iii) To measure the strength and hydraulic characteristics required as model inputs for two major soil types of the semi-arid tropics.
iv) With our collaborators, to monitor seedbed physical properties and seedling emergence for subsequent development of a process-based model of seedling emergence.
v) To compare predictions made by the soil water and temperature model, SWEAT (developed at Reading University), with field data collected in Tanzania.
vi) Production and testing of a prototype crop emergence model (EMERGE) for sorghum, using laboratory data from phase 1 (EMC X0213) and field data from Tanzania.
vii) Sensitivity analysis of EMERGE to identify elements needing further development for field use.

Research Activities

((i) Measurement of seedling germination and growth parameters under differing conditions of soil matric potential, temperature and mechanical impedance (EMC X0213))
(ii) Fitting of functions for data derived in (i) above, to use in the model
(iii) Development of a spreadsheet version of a seedling growth model (GEMA) incorporating functions for thermal time to germination, respiration, growth rates of root and shoots vs temperature, matric potential and mechanical impedance, and lethal temperatures for roots and shoots.
(iv) Development of functions for predicting mechanical impedance from matric potential within the body of the soil and near the soil surface.
(v) Lab work to calibrate the filter-paper technique for determining matric potential in the field
(vi) Fieldwork at 2 sites in Tanzania (total 10 man months):
   a) to determine rates of germination, growth and emergence or death of sorghum and cowpea seedlings in two different soil types under realistic sowing scenarios, with and without a mulch.
   b) to determine rates of evaporation from soil.
   c) to collect weather data, soil temperatures and measurements of soil matric potential in seedbeds during the period between seed sowing and seedling emergence or death.
   d) to measure strength and water release characteristics of soils from the two sites for use in the model.
(vii) Validation of SWEAT and GEMA using field data collected in (vi) above.
(viii) Writing of a user-friendly, windows-based version of a seedling germination and emergence model (EMERGE) incorporating (iii), (iv), and the soil water and temperature model, SWEAT, developed at Reading University.
(ix) Using EMERGE to study the likely effects of changing parameters such as sowing time, sowing depth or amount of rainfall.
(x) Development of a set of rules to generate synthetic hourly values (required to run the model) from daily values (as usually measured).
(xi) Dissemination of the model and manual to individuals at academic and research institutions worldwide for use and comment.

Outputs

The principal output from the project is the EMERGE model and manual (objective (vi)). This incorporates the soil water and temperature model, SWEAT which is used to generate values of matric potential and temperature in seedbeds given hourly values of meteorological data. As meteorological data is more usually recorded on a daily basis, methods for generating plausible, synthetic hourly values from daily values have been developed and are given in the EMERGE manual (objective (ii)).

Fieldwork and subsequent lab work were used to improve the little used filter-paper method for measuring soil matric potential (Deka *et al*, 1995) which was used in determining the hydraulic characteristics (Daamen, 1995) and strength characteristics (Townend *et al*, 1996) of the soils at our two sites (objective (iii)). Outputs from SWEAT were validated using field data collected in Tanzania at our two experimental sites during field campaigns in 1993 and 1994. Treatments included cultivation and no cultivation at one site and mulching or no mulching at the other, with different amounts of simulated rainfall (10, 20 or 30 mm). These have been presented by Daamen (1995). The SWEAT model has also been extended to predict mechanical impedance in seedbeds using the new strength characteristics (objectives (i and v)).

The field experiments in Tanzania included detailed measurements of matric potential (from which mechanical impedance can be estimated) and temperatures in the seedbeds, together with daily measurements of root and shoot length and percentage emergence for the growing seedlings using destructive harvesting (objective (iv)). These enabled us to draw conclusions about the degree and causes of seedling failure (Townend *et al*, 1996).

The growth model part of EMERGE has been validated independently of SWEAT using the directly measured values of soil matric potential and temperature and comparing the outputs with measured values for seedling growth and emergence. The results of this are given in the EMERGE manual (Mullins *et al*, 1996). The complete model has then been used to show the effects of altering various input parameters on seedling emergence (objective (vii)).

Limitations of the seedling growth model are discussed in the User's Guide (Mullins *et al*, 1996) and of SWEAT in Daamen (1995) (objective (vii)). In particular the model does not yet have functions describing the duration of any damaging but non-lethal effects of high temperatures on seedlings, or the effects of limited aeration in seedbeds due to waterlogging (which can occur in structureless soils such as that at Ismani, after heavy rain). Growth functions are also modelled using mean values but could be improved by taking account of the spread of data, as is already done for thermal time to germination. The SWEAT model provides good predictions of evaporation and temperatures. At present, predictions of matric potential in the depth range 2 - 4 cm (critical for seedling growth modelling) are wetter than those found in the field. The model could be improved in this respect by taking account of turbulent flow and changes in bulk density which occur near the soil surface. The effect of a mulch is modelled as an increase in aerodynamic resistance above the soil together with a reduction in net radiation. Further work could improve this prediction and allow the effects of different types of mulch to be studied.

The main findings from the project are:

- Emergence of both sorghum and cowpea in the field in Tanzania was often very low (0 -10%) under realistic scenarios. This was usually due to physical conditions in the seedbed during pre-emergent growth rather than poor germination (Townend *et al*, 1996), although the problem was generally referred to by farmers and agriculturists as "poor germination" (Mullins and Mtakwa, 1995). It was shown that under different scenarios, high temperatures, low matric potential (i.e. lack of water) and high mechanical impedance could all be responsible for failed emergence (Townend *et al*, 1996).
- Addition of a mulch generally had only a small, or no effect on emergence. Evaporation was lowered slightly for the first one to two days (Daamen, 1995) but growth rate was also slower due to lower temperatures. The overall effect on seedling emergence was small or none (Townend *et al*, 1996).
- The EMERGE model suggests that percentage emergence could be affected dramatically by small changes in sowing practice. A scenario was set up using measured weather and soil parameters and measured parameters for sorghum (var tegemeo) from phase 1(EMC X0213). A range of inputs of sowing time, rainfall and sowing depth and their resultant effect on modelled emergence are shown below:

rainfall (mm applied to soil at -1 MPa)	sowing depth (mm)	sowing time (hours before rain)	% emergence
30	60	22	89
30	90	22	14
30	60	16	47
30	60	3	0
25	60	22	61
20	60	22	3
10	60	22	0

(N.B. in these scenarios, the soil was wet enough to permit germination but not sufficiently so as to be favourable to growth until after the rain. Consequently, increasing the number of hours before rain at which the seeds were sown has allowed seeds to start germination before the rainfall. These results are discussed further in Mullins *et al* (1996))

Contribution of Outputs

The development, dissemination and use of a crop establishment model that can make use of local climatic, soil and crop information (which is the goal of this research) will allow farmers to gain better familiarity with what combinations of conditions (e.g. sowing dates in relation to rainfall, sowing depths) are likely to lead to poor establishment, and why this is likely to occur (soil temperature, dryness, hardness). Hence they will also be able to understand the potential effects of intervention strategies such as mulching, seed priming, crust breaking, and adjusting sowing date and depth, for their particular circumstances. This will reduce crop failure at establishment and hence increase overall yield, since scarce sowing opportunities will be more effectively used.

The model and manual has been sent to around 70 individuals at academic and research institutions worldwide for use and comment. Outputs from the research have also been disseminated through published papers and internal reports:

Deka RN, Wairiu M, Mtakwa PW, Mullins CE, Veenendaal EM and Townend J (1995). Use and accuracy of the filter-paper technique for measurement of soil matric potential. European Journal of Soil Science, 46: 233-238.

Townend J, Mtakwa PW, Mullins CE and Simmonds LP (1996). Soil physical factors limiting establishment of sorghum and cowpea in two contrasting soil types in the semi-arid tropics. Soil and Tillage Research (in press).

Mullins CE and Mtakwa PW (1995). Report on farmers experience of crop establishment problems in two districts in Tanzania. (Internal report circulated to NRI, SUA, Tanzania, and UK collaborators).

Daamen CC (1995) Tanzania Field Campaign - November 1994: Summary of results - Evaporation from soil. (Internal report submitted to NRI).

Mullins CE, Townend J, Mtakwa PW, Payne CA, Cowan G, Simmonds LP, Daamen CC, Dunbabin T and Naylor REL (1996). EMERGE - Users Guide (Report and computer model circulated to NRI, collaborators, and worldwide to academic and research institutions).

In order to achieve the full benefit from this work further development of the emergence model (EMERGE) into a full establishment model (GEM) will be required. These can then be taken to researchers and farmers in Tanzania to demonstrate the potential of the modelling approach for future research, and to provide education and advice for improved crop establishment in the field. This will ultimately contribute to ODA's goal of improving productivity / production potential of the Semi-Arid Production System, leading to social and economic benefits in the Developing Countries of the Semi-Arid Tropics.

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