Importance of Soil Inputs and Challenges in Simulating Soil Effects in Low Input Systems

Providing Accurate Inputs and Initial Conditions

CIMMYT (Nepal) – March 18-22, 2013
ICRISAT (India) - March 25-29, 2013
A Few Examples of the Problem

- There are inherent soil fertility differences within a field or region, even when rainfall is not limiting.
- Decreased fallow periods between cropping seasons, little or no inorganic fertilizer, no irrigation
- No-till vs. conventional tillage cropping systems, impacts on soil C and crop productivity
- Nutrient (N or P) leaching under intensive irrigation management or in high rainfall areas
- Eroded soils
- Low input systems
A Few Questions

- How can we account for inherent soil fertility differences within a field or region?
- What are the most critical soils inputs for accurate (adequate?) predictions?
- How accurate do the inputs need to be (for various types of crop and soil model inputs)?
- Can cropping system models simulate crop and soil responses for cropping systems in degraded soils and stressful climates?
- What are uncertainties associated with model predictions under such harsh conditions?
Potential vs. Actual Production Levels

• Maize
  – Typical yield in West Africa – 1,000 kg/ha
  – Potential yield for variety and climate – 8,000 kg/ha

• Peanut
  – Typical yield – 800 kg/ha
  – Potential yield for variety and climate – 3,800 kg/ha

• Why?
  – Can the models simulate these ranges of yield?

• These are site-soil-specific problems

• Model ability to mimic these responses
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Applying the Model for Crop Production

• Adapt model to local conditions.
  – Models have many coefficients and input requirements: Cultivar traits, soil inputs, and management history
  – First comparison of simulated vs. observed shows large deviations; why? What would you do next?

• Evaluate predictive quality.
  – One needs data before evaluating how well a model predicts crop & soil outputs for specific locations, conditions.

• Analysis of management options, effects of climate, soil, on yield, water management, soil C, etc.
  – Soil fertility management
  – Water management
  – Climate impacts
  – Variety selection, planting date, etc.
Are you a “Crop Model Detective”? 

• What if model predictions do not agree with observations? What are examples of this? 
• What factors would you look for that may be the cause of this discrepancy? 
• Do you think that this can be improved? 
• If so, what steps would you take to remedy the problem? 
• How would you know that you have solved the problems? 
• *Systems Thinking!!!*
What Inputs? Coefficients?

• Diagnostic needed before estimating coefficients

• Main reasons for lack of agreement between model & observation:
  – Errors in data
  – Inaccurate genetic coefficients
  – Inaccurate soil parameters (water, N, nutrients)
  – Inaccurate initial conditions
  – Incomplete model (example, salinity)
  – Model errors (conceptual, implementation)
What Inputs? Coefficients?

- Initial conditions
  - Soil water
  - Soil organic matter
  - Soil mineral N
  - Soil phosphorus
- Soil water parameters
- Soil organic matter parameters
- Genetic coefficients
Initial Soil Conditions

• Needed for simulating specific experiment
  – When to start simulation?

• Soil water
  – Initial water content through the profile

• Available mineral N (NO₃, NH₄)

• Soil organic matter
  – Organic C
  – Organic C:N and C:P ratios
  – Initial organic matter pools (microbial, slow, stable, inert)
  – Initial surface residue amount and characteristics
Errors

- Errors increase (accumulate) with simulated time after setting initial conditions, even if the initial conditions are good.
  - Daily & Hourly time step
- Especially true for soil C balance.
- Soil water balance “may” re-set with leaching rains.
- Implications are that long-term simulations may diverge from observed due to model errors; also errors in initial conditions, errors in inputs, etc.
Soil water parameters

• Soil texture
• Water holding and drainage characteristics:
  – LL, LL-15,
  – DUL,
  – SAT,
  – air dry,
  – CN,
  – KSAT,
  – SWCON
• Plant related soil water variables:
  – CropLL, KL, XF (APSIM)
  – SRGF, SLPF (DSSAT)
Soil organic matter parameters

• Initial C fractions
  – Laboratory C fractionation
  – Previous cropping history
  – Soil texture - Adiku equation

• Initial residue characteristics
  – Previous crop and management
  – Biomass left in field from prior season
  – Duration of fallow period

• Decomposition rates
  – Base rates modified for temperature, water, soil disturbance, soil texture
Genetic coefficients

• Genetic Coefficients
  – Development
    • Flowering, physiological/harvest maturity
  – Biomass growth
  – Grain growth/partitioning
  – Height (stick) function
Soil Water - How?

- Estimation using pedotransfer functions
  - Need texture and other information available from soil survey data. BUT, although this approach gives reasonable representative values of soil parameters, it is unlikely that these will suffice for accurate evaluation in specific fields.
  - Documented in "Soil Matters" available on the APSIM wiki.
  - SBuild soil utility in DSSAT
Soil Water - How?

• Laboratory estimates of LL, DUL, SAT
  – Difficulty in estimating DUL, even though LL can be approximated by soil water at -15 bars
  – Lab results are used for pedotransfer function (so more confidence in LL, less confidence in DUL, especially as % clay increases)

• Field measurements
  – Best approach
  – Examples

  Most common problem is too small (DUL-LL)
DUL estimation, bare soil; TDR measurements

Soil Water; Field Measurements

MicroWex4 Corn 2005

Soil water content (fraction)

DUL(?)

LL
Soil Water; Lower Soil Water Availability (LL)
Other Soil Water Parameters

- Curve number used to compute infiltration rate.
  - Modified for surface residue cover
  - Does not work well for cracking clays or vertisols.
- Ksat - can be used to create temporary “perching” of water
  - Ksat is a simple parameter, but difficult to set.
- SWCON
  - Drainage fraction per day
- Water table parameters (how to set?).
  - Are you getting upward flux of water?
Root distribution function

- (DSSAT: SRGF, APSIM: XF)
- relative factor (0-1), 1.0 for topsoil
  - exponential decay
  - usually causes more water deficit than observed!

- PP = depth of top soil (cm)
  = 20 cm in this example
- RD = maximum rooting depth (cm), or depth at which the value is 2% of the maximum value
  = 120 cm in this example

Common problem: too little distribution of roots at depth
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Enter SLPF manually

Set SLPF to mimic slow DM growth under water and N sufficient conditions. 1.00 is maximum possible (good Midwestern soils in USA)
*IBSB910015  SCS  FSA  180 Millhopper Fine Sand
@SITE  COUNTRY  LAT  LONG  SCS  FAMILY
Gainesville USA  29.630  -82.370  Loamy,silic,hyperth Palo
@  SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
-99  0.18  5.0  0.50  66.0  1.00  0.92  IB001  IB001  IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI
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Ksat of 0.1 or less to restrict flow from layer to layer
Total biomass growth (kg/ha) simulated with, and without P fertilizer, both with fungicide treatment. On-farm peanut trial in Ghana.

SLPF was adjusted so simulated crop mass matched the slope of observed crop mass. No water or N limitations.
Total biomass growth (kg/ha) simulated with, and without P fertilizer, both with fungicide treatment. On-farm peanut trial in Ghana.

Effect on pod mass production depends on increase in SLPF (from P fertilizer) and loss of LAI (Pest - PCLA input)

What would you do as “Model Detective”?
Soil Organic Matter

• Important for N fertility, especially under low fertilizer inputs or Best Management Practices (BMP)

• Total C
  – Soil survey data
  – Field measurement
  – Estimated using field history
  – “Start-up” simulation

• Fractions in microbial, active, slow and inert C pools
  – No single direct measurement method is used
  – APSIM specifies Walkley Black lab procedure
  – Estimated using “start-up” simulation with the model based on field history, soil texture, climate and total organic C
Soil Organic Matter

• Plant material that has not yet been decomposed by microorganisms

• DSSAT: 5 pools
  – Fresh organic matter
    • Metabolic – very fast decomposition
    • Structural – fast decomposition
  – Soil organic matter
    • Active (SOM1) – Microbial C, fast decomposition
    • Intermediate (SOM2)
    • Passive (SOM3) – Stable Soil C, slow decomposition

• Measurements of Total Organic C includes all the above pools
Soil Organic Matter

- APSIM: 4 pools
  - FOM (Fresh organic matter e.g. roots) which decomposes rapidly.
  - FBIOM - the microbial biomass pool which decomposes more slowly
  - HUM - humic pool which decomposes very slowly. Calculated from other parameters.
  - FINERT – fraction of the OC is considered inert - no decomposition (higher at depth) so this could be considered a fourth pool that doesn't decay
- Measurements of Total Organic C includes all the above pools
Inputs for Soil N Processes

• The following need to be provided for each soil layer:
  – Bulk density (g/cm$^3$)
  – Organic carbon (%) (APSIM Walkley Black %)
  – Total nitrogen (%) (DSSAT uses C:N ratio of 10:1 if not known)
  – Soil pH (in water)
  – Organic matter pools
  – C:N ratios, each pool
  – Decay rates, each pool
  – For surface layer: need fresh organic matter (prior crop residue = litter), its distribution and composition, and fraction incorporated.
Importance of Initial C Pool Fractions

**Figure 11.** Simulated changes in soil C over a 20-year period demonstrating the effects of different soil C pool fractions. Total soil C was initially the same for both simulations. Triangles are for default C pool fractions and the squares represent a soil with a low fraction of active soil C (SOM2) using DSSAT Century (Gargiulo, unpublished).
Cultivar Coefficients

- Cultivar coefficients (GC’s) govern life cycle and reproductive growth rate
- Cultivar coefficients and definitions are located in the cultivar file (DSSAT) or “ini” file (APSIM)
- Cultivar coefficients are cultivar (hybrid or inbred) specific
- Must be estimated from data (field experiments or crop breeding trial data)
Concluding Comments

• A model is always wrong - what is important is to what degree

• In *most* situations, soil parameters are much more important than cultivar coefficients
  – Usually when crop biomass and yield has high error, it is because the soil is incorrectly parameterized and the water balance is off
Concluding Comments

• Some parameters and initial conditions are difficult to measure
  – Proxy measurements for estimation. Often estimated by expert opinion from field history. e.g. previous crop recently harvested will have dried profile out and depleted nutrients. Similarly a fallow without weed control.
  – Inverse modeling, similar process for soil and cultivar coefficients (calibration)

• Limitations will always exist in models, but capabilities of models are notable and allow many practical and useful applications, even under difficult environments – when done carefully
Agriculture is Highly Variable over Time & Space

- Soil and crop coefficients are needed
- Crop coefficients should be estimated under non-stressed conditions
- Accurate soil inputs are difficult to obtain in many situations
- Initial conditions are critical inputs
- Cropping history of a field is important