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Models of physiological stresses for agricultural systems

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Modelling of agricultural systems needs to take into account abiotic, physiological stresses. To be useful as decision aid, models must be quantitative and robust. Simplified models simulating stress action and impact, suited to the relevant scale and the available data, are embedded in the mathematical representation of the larger production or cropping system. The boundaries of this larger system have to be carefully defined according the objectives and relevant factor interactions. The ideal model is in this respect minimalist, unless the intention is to use the same model for a range of problems and/or crops. Two successful “minimalist” models for Sahel, RIDEV and SARRA, are presented as examples.

RIDEV (developed at WARDA, Senegal) simulates heat- and chilling-induced spikelet sterility of irrigated rice as a function of site, sowing/transplanting date and variety, thus aiming at optimising cropping calendars on the basis of risk analyses. The model simulates crop phenology as a function of microclimate and photoperiod, and predicts thermal damage to reproductive organs occurring during critical development stages. Risks of crop failure owing to thermal stresses are estimated on the basis of historical climate. Simulation of crop duration, highly variable according to season, can be used to estimate water demand for irrigation. RIDEV has been extensively used in agronomic research, extension and crop improvement.

SARRA (developed at CIRAD, France) simulates drought risks for dryland cereals in the Sahel. A water balance is simulated on the basis of atmospheric demand (ETP), a developmental stage dependent crop coefficient (Kc) enabling calculation of maximal crop ET (ETM = Kc * ETP), and a dynamic root front (limited by the wetting front, thermal time and genotype) which sets the size of the soil water reservoir. The fraction of transpirable soil water (FTSW) acts as a brake on transpiration using the Eagleman equation. The ratio of real over maximal transpiration (ETR/ETM) acts as a stress index. Integrated over the season and weighted according to stage, this index is converted into a yield index that can be easily calibrated with field data. SARRA is widely used for zoning exercises and, when coupled with Meteosat data, for yield forecasts in the Sahel (Agrhymet, Niamey).

Simple stress models such as RIDEV and SARRA can be surprisingly robust, but they require complementary information to be used as decision aids. Consequently, many attempts have been made to devise models integrating many crops, stress factors and cultural practices (ex: DSSAT, APSIM, STICS). Such encyclopaedic, multi-purpose programs rarely serve their declared purpose as “decision support” or “expert” systems, but have substantially stimulated research by bringing scientists together. The broad use of biological simulation models in agricultural production, research and education, however, remains the exception, despite the fact that we need them as badly as the pilot needs his instrument panel and the administrator his spreadsheet – as an extension to the cognitive and computing capacities of our brains. In many cases, not the complexity the model but that of its programming environment deters the potential user. This needs to be improved to enable researchers and practitioners to freely apply the “what-if” test to their hypotheses and data. A RIDEV or SARRA can stand at the end of many a thesis and help bridging the gap between hard core stress physiology and agricultural reality.