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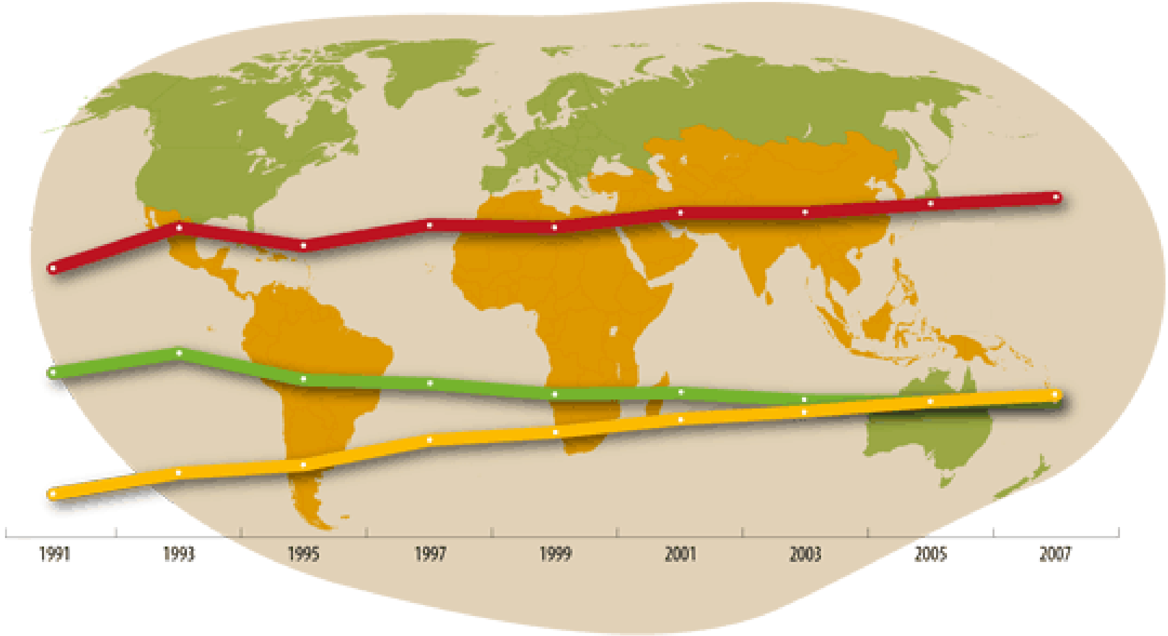
CIP

Drought and heat tolerance evaluation in potato (*Solanum tuberosum* L.)

P Monneveux, DA Ramírez, A Khan, RM Raymundo, H Loayza, R Quiroz

- potato, 4th most produced food crop (370 million tons)
- grown on 19 million ha worldwide (FAOSTAT 2013)
- developing countries produce more than half of the total world potato (FAO 2009)
- only crop with soya for which contribution of developing countries to world production is growing (Walker et al. 2011)



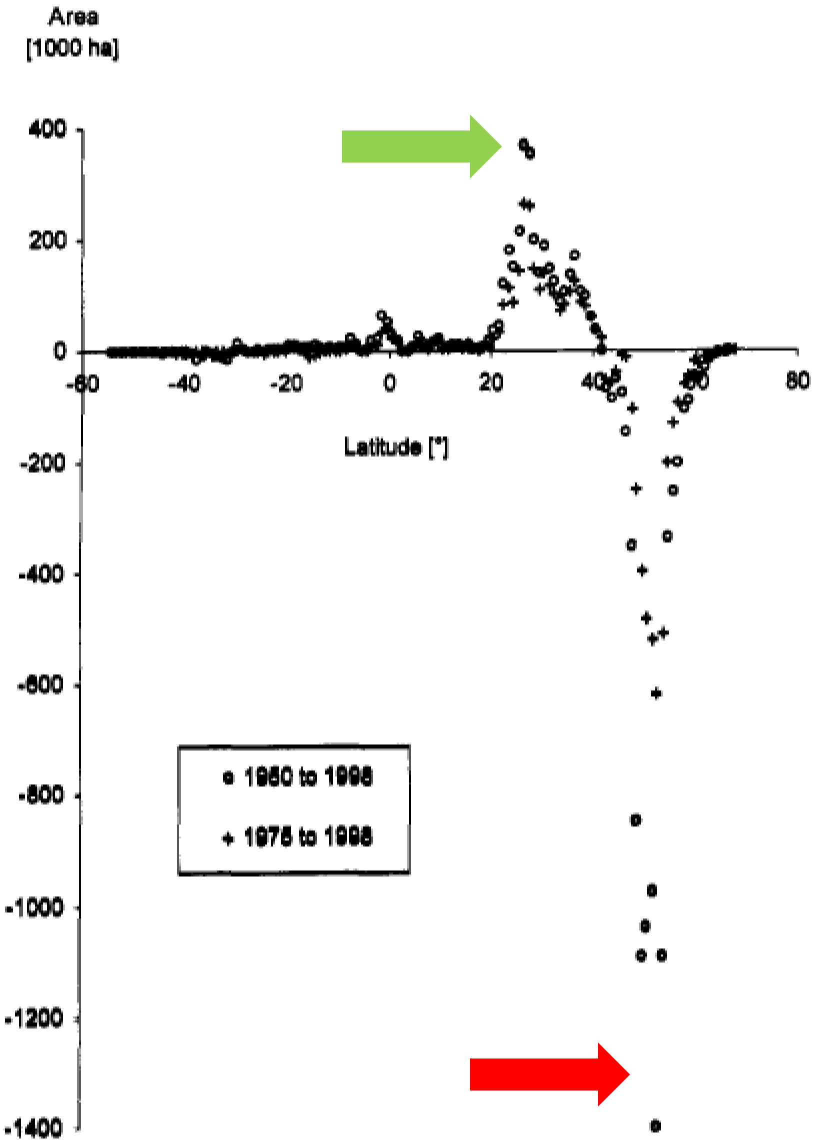
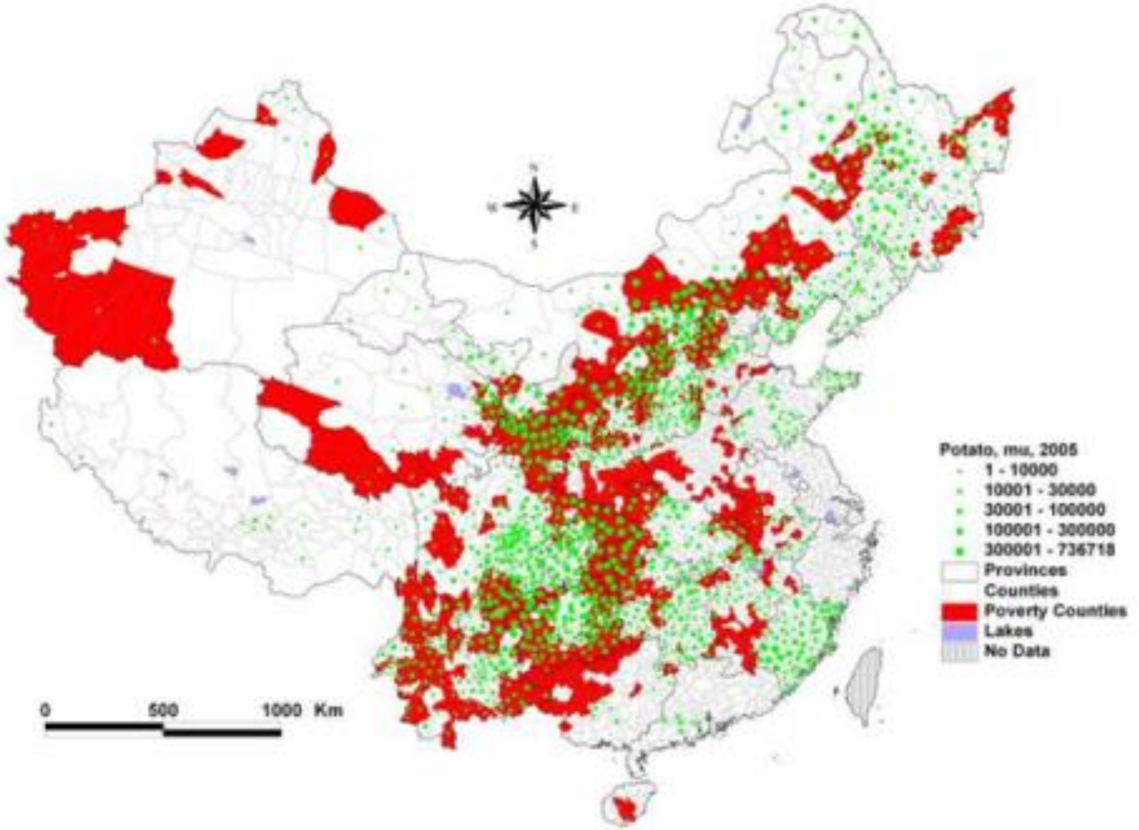


FIGURE 5.
Change in potato area between 1950 and 1998, and between 1975 and 1998, by latitude. Each dot represents one-degree latitude. Latitude in the southern hemisphere is indicated with a minus (-) sign.

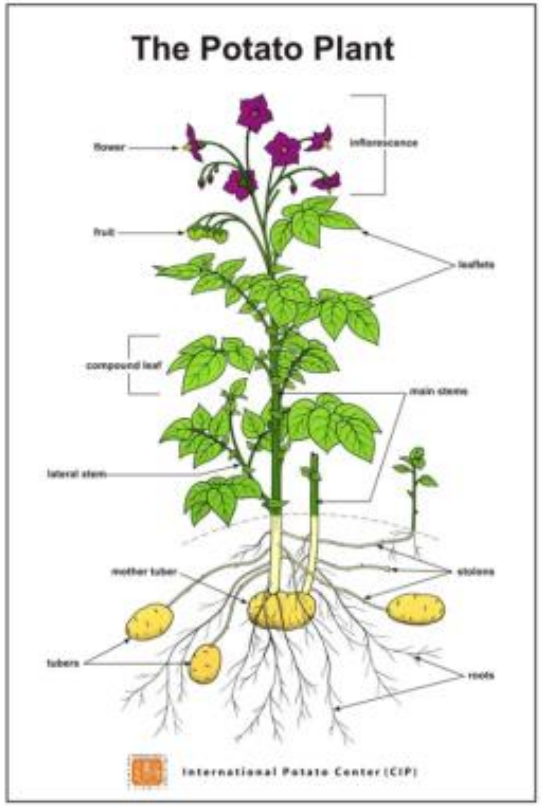
Hijmans RJ, Amer J of Potato Res (2001) 78:403-412

- in developing countries, increase in production mainly due to an increase in cultivated area (Walker et al. 2011)
- in many areas, potato suffers water stress and heat stress, particularly in the subtropics (Simmonds 1971)
- impact of abiotic stresses on potato production will increase over the next decades, due to climate change and the extension of potato cultivation under drought/heat conditions (Hijmanns 2003)



- cultivated in remote/marginal areas by poor farmers with limited access to farm inputs (Scott 1985)
- contributes to dietary energy intake and hunger reduction (Thiele et al. 2010)
- higher market value, contributes to poverty reduction (Scott et al. 2000)

- potato is susceptible to drought (Monneveux et al. 2013)
- shallow root system, low capacity of recuperation (Iwama & Yamaguchi 2006)
- drought decreases plant growth (Deblonde et al. 2001) and number (Eiasu 2007) and size (Schafleitner et al. 2007) of tubers
- the magnitude of drought effects depends on timing, duration and severity of the stress (Schafleitner 2009)



- high temperature drastically affects potato production
- soil temperature higher than 18^{o}C tends to reduce tuber yield, especially when combined with high ambient air temperature
- heat stress creates imbalance in source-sink relation, delay in tuber initiation and bulking and malformation and necrosis of tubers (Levy and Veilleux 2007)

N.A. Streck et al. / Agricultural and Forest Meteorology 142 (2007) 1–11

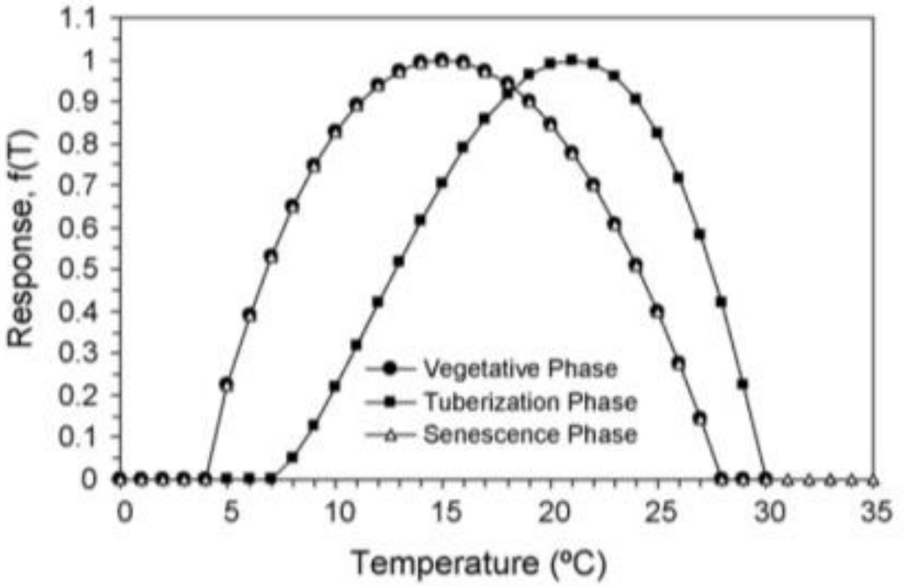


Fig. 2. Temperature response function [$f(T)$] of the WE model, Eqs. (4)–(7), for the vegetative, tuberization and senescence developmental phases of potato.

- today, the progress of genomics and bioinformatics (eg, availability of genome sequence offer real opportunities for dissecting genetic basis of drought and heat tolerance (Monneveux et al. 2013)
- further progress however depends on our capacity to generate the high-quality quantitative data needed for genetic analysis and gene identification and transfer (Tuberosa 2012): phenotyping, main bottleneck in breeding for abiotic stress tolerance

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Review

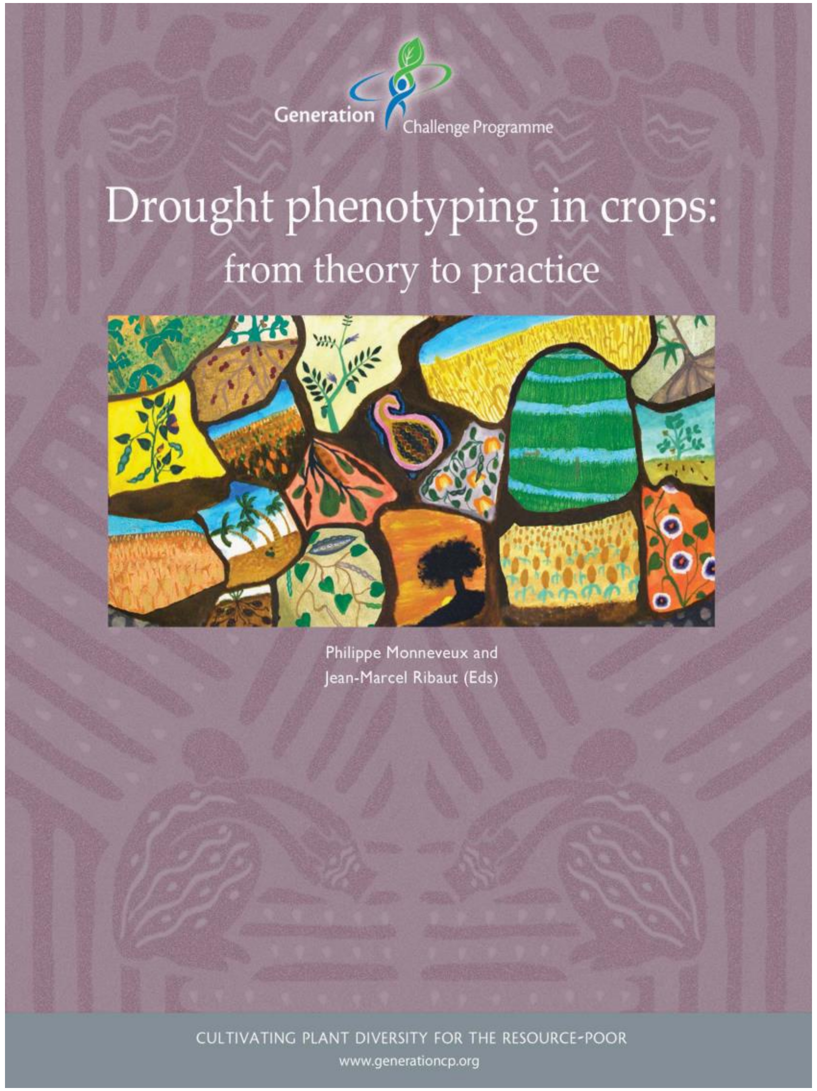
Drought tolerance in potato (*S. tuberosum* L.)
Can we learn from drought tolerance research in cereals?

Philippe Monneveux[a,*], David A. Ramírez[a], María-Teresa Pino[b]

[a] International Potato Center, Lima 12, Peru
[b] Fisiología & Genética Vegetal, Instituto Nacional de Investigaciones Agropecuarias (INIA), Santa Rosa 11610, Chile

Plant phenotyping

- basic measurement of individual quantitative parameters that form the basis for the more complex traits
- over the last two decades, progress done in traits measurements
- efficient phenotyping implies accurate i) definition of target population of environments, ii) characterization of the testing environment or managed stress environments (MSE), iii) stress monitoring and characterization and iv) measurement of secondary traits

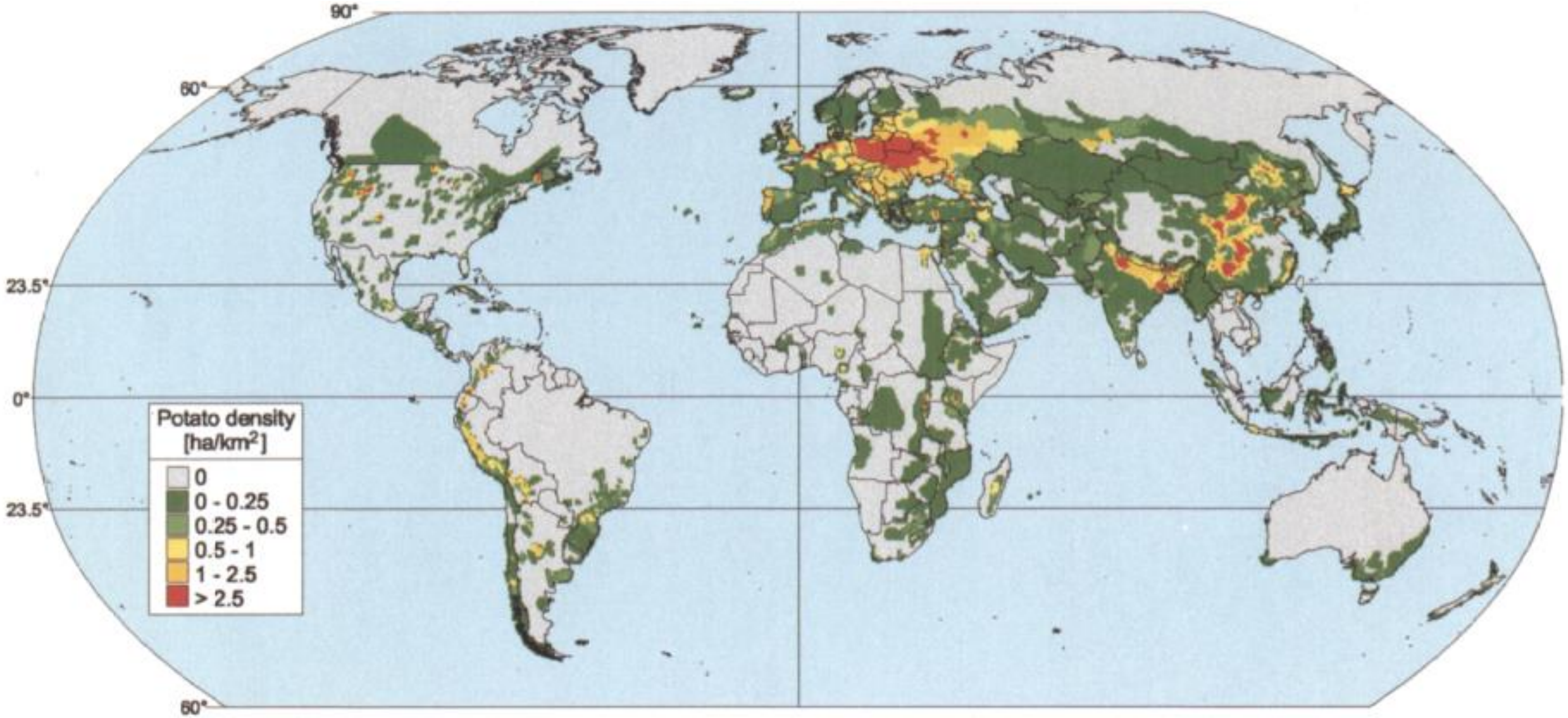


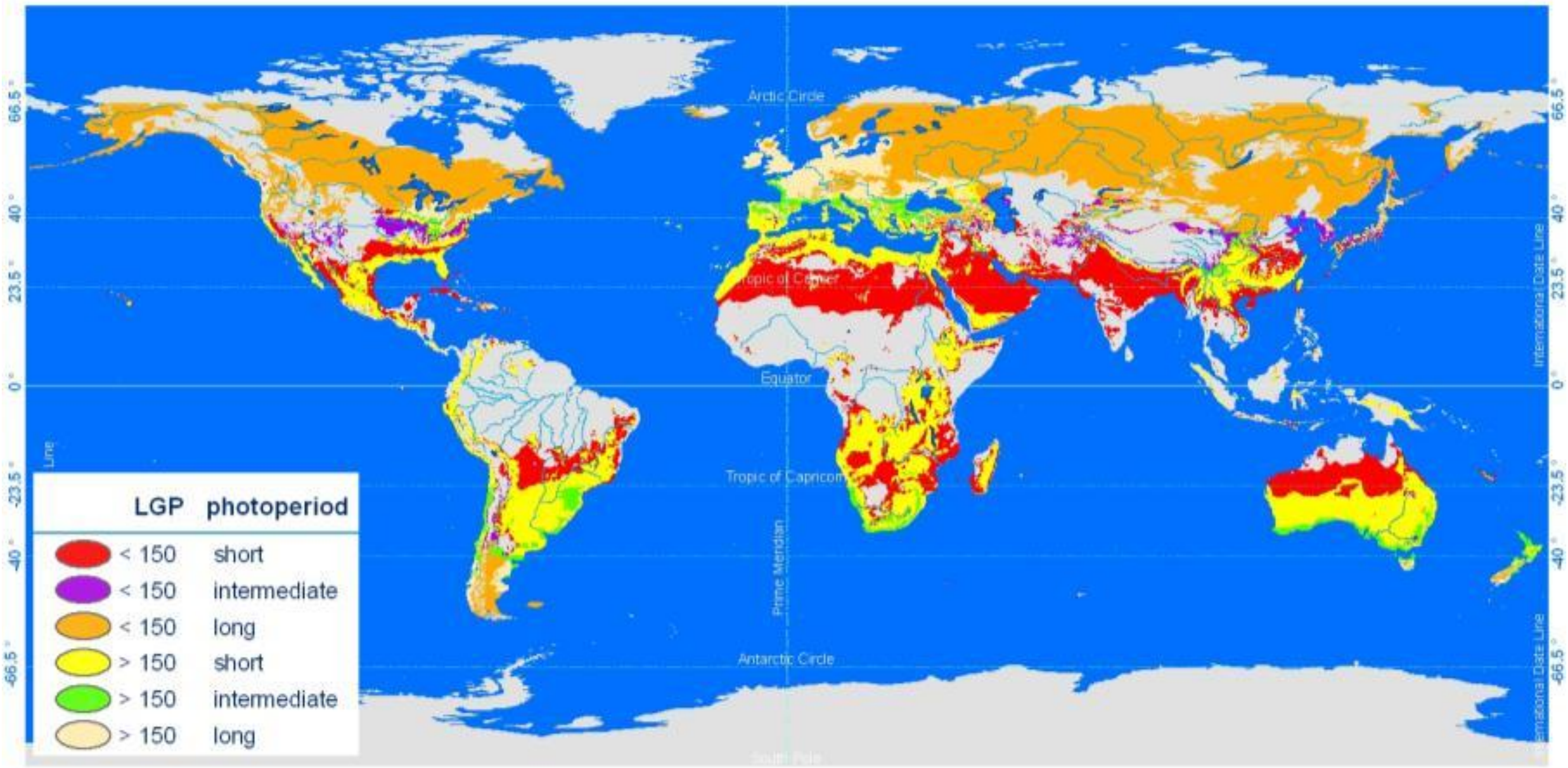
Definition of potato target populations of environments

- any variety is adapted to several environments, referred by Fischer et al. (2003) as target population of environments (TPE)
- TPE defined as the set of environments in which an improved variety is expected to perform well (Cooper et al. 1997)
- important to clearly define the TPE for which a variety is developed

Mega-environments or agro-ecological zones

- definition of ME based on crop distribution and environmental constraints (Rajaram et al. 1995)
- potato distribution: Finch and Baker (1917), Van Royen (1954), Bertin et al. (1971), Hijmanns (2001) using country-level statistics and geo-referenced databases





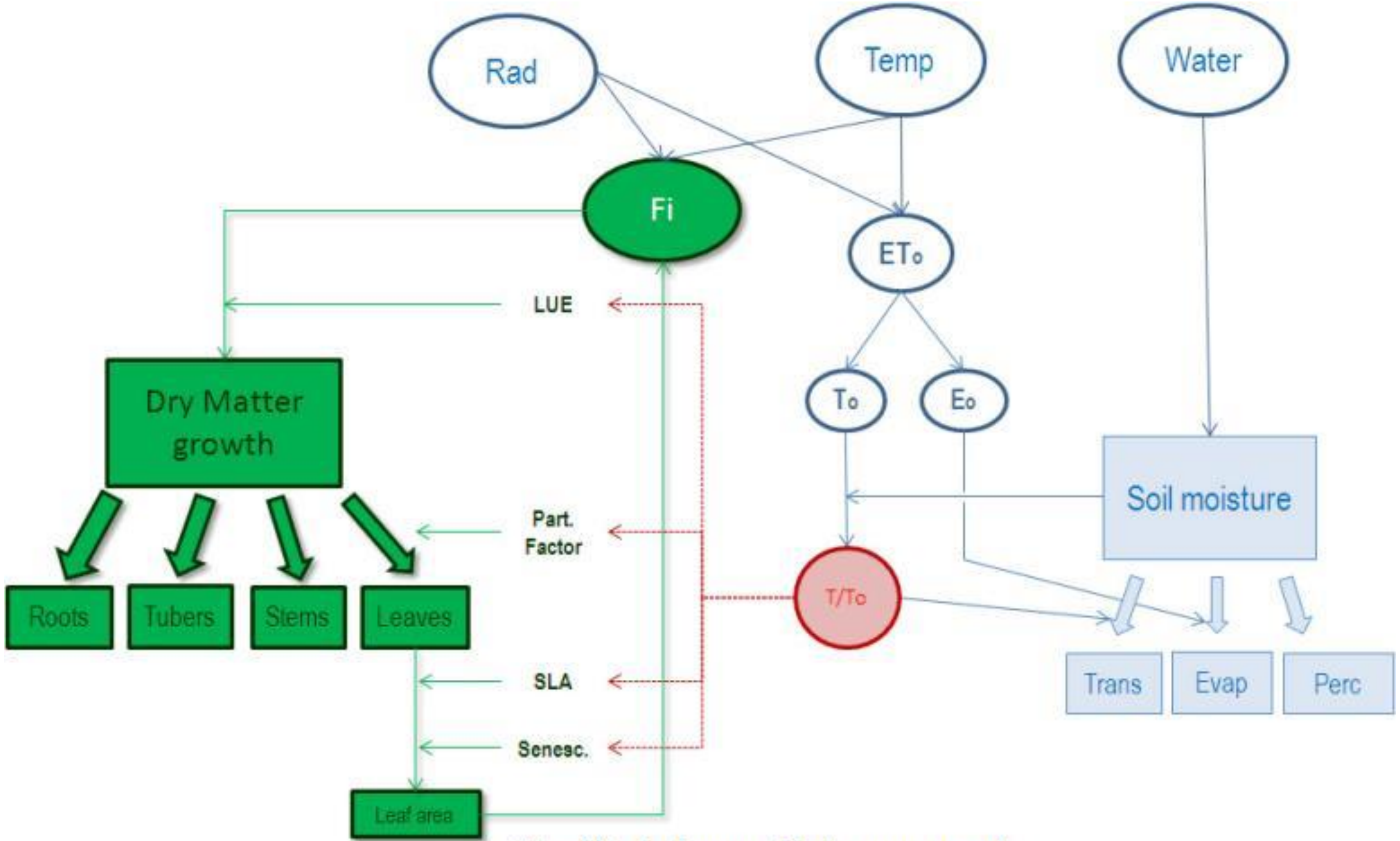
- dry matter accumulation depends on the amount of solar radiation intercepted by the crop (LGP) while partition is determined by temperature and photoperiod (van Keulen and Stol 1995)
- as a consequence, growth, development and yield of potato highly depend on latitude and altitude (Haverkort 1989)

Use of genotype by environment interaction (GEI) analysis

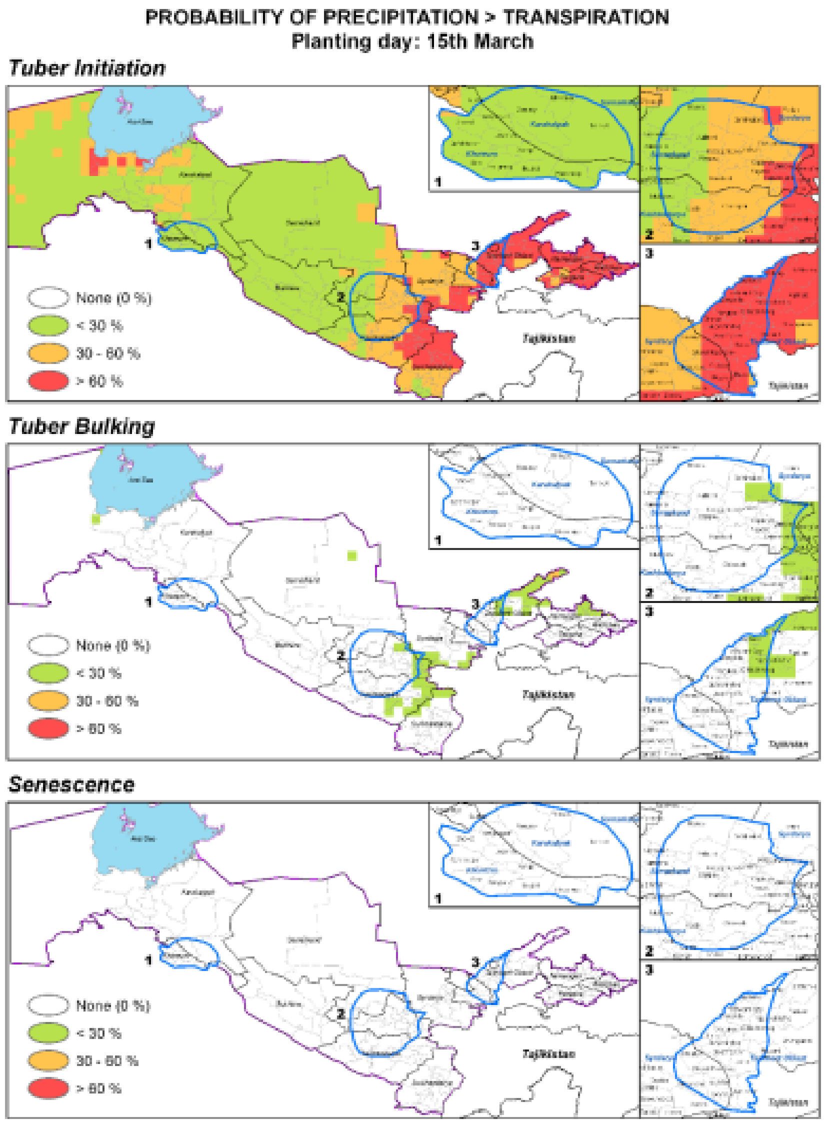
- analyzing GEI (using biplot analysis and AMMI and GGE models) allows describing the behaviour of genotypes across environments and defining clusters of locations sharing the same best cultivar(s) (Yan and Rajcan 2002)
- in potato, information and historical sets of data poorly exploited to cluster environments (seed distribution issues)

Use of spatial analysis and modeling

- CIP is using soil and climate information on the trial sites to classify locations into more or less homogenous environment types
- use of spatial analysis and development of models



Simplified scheme of daily crop growth

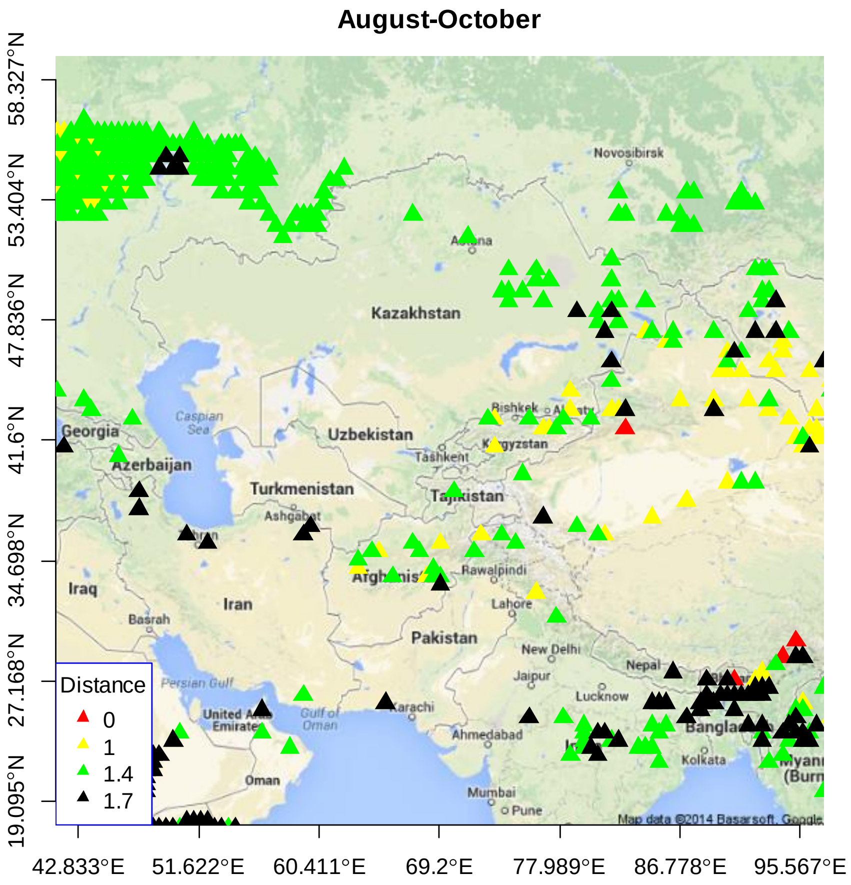


Main potato cropping area in the lowlands of Uzbekistan (blue lines) and probability of drought (precipitation/crop transpiration) at three crop developmental stages during the March-June cropping season.

- long-term precipitation records obtained from daily TRMM 3B42 v7 data base in target areas
- correspondence with measured precipitation verified
- drought probability estimated for 3 phenological stages: TIO, tuber bulking and senescence
- crop growth model parameterized using SOLANUM model with promissory clones in drought prone areas (Carli et al. 2014)
- environmental classification established
- simulation results validated through field evaluation

Choice and characterization of the managed stress environment (MSE)

Choice of the managed stress environment (MSE)



Statistical distance (Euclidean) comparing Santa Rita experimental site in Peru with zones located in the Central Asia Region during August-October growing period

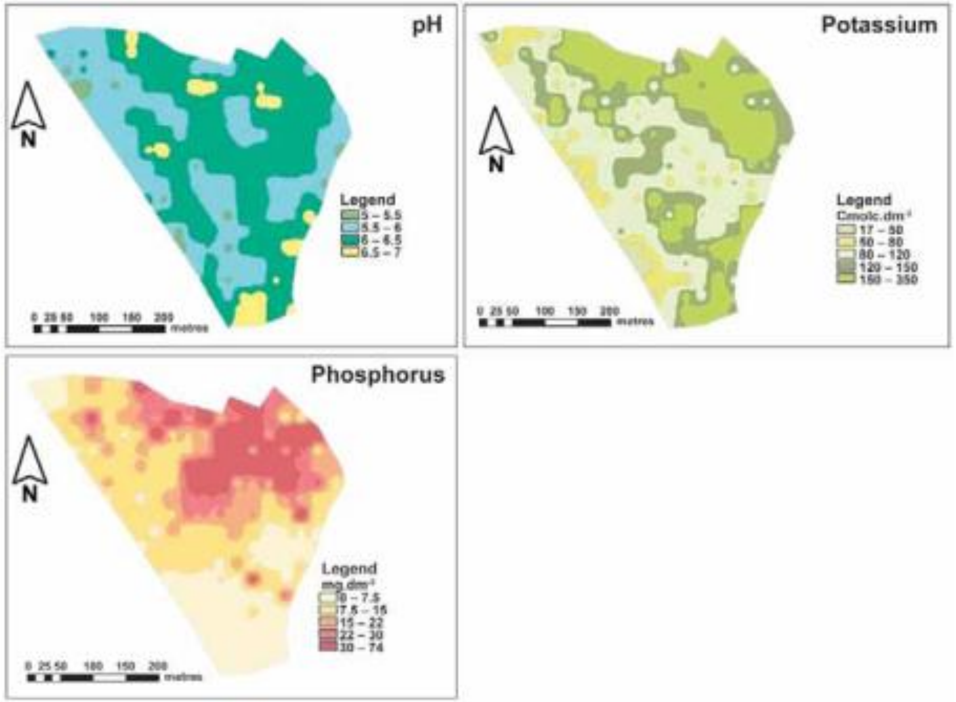
- the choice of MSE should take into account representativeness with regard to TPE based on historical weather data and soil features
- deviations may result in significant GEI between TPE and MSE, and genetic gains achieved in the MSE may not be expressed in the TPE
- geographic information system (GIS) tools (homology maps) and models help describing the relationships between TPE and MSE

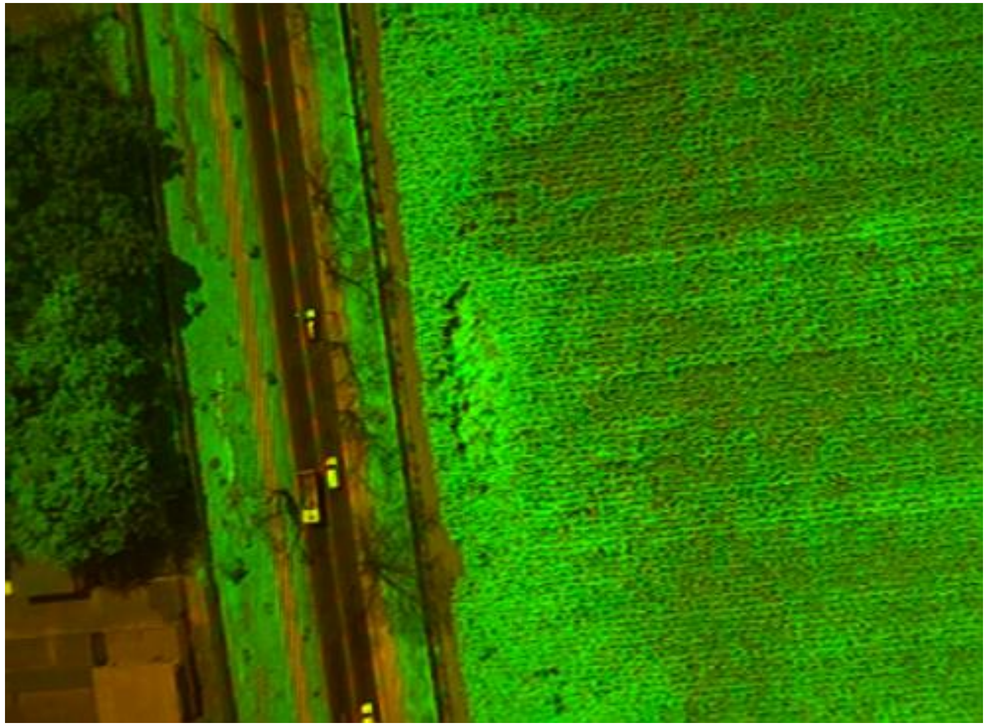
Characterization of managed stress environments

- quantify evapo-transpiration and crop water requirements to control the different water treatments and estimate the corresponding crop stress levels
- main atmospheric parameters and soil characteristics (water holding capacity)
- water balance models are useful to predict water availability (e.g., aquacrop, http://www.fao.org/nr/water/aquacrop.html)

Reducing noise factors

- additional stresses that exacerbate the effects of the studied stresses and biases the evaluation of the effects of drought and heat
- soil surveys permit to describe the distribution of these confounding factors
- ensure minimal environmental heterogeneity to reduce unwanted experimental error (penetrometers, soil electrical conductivity sensors and spectral reflectance and thermal imagery techniques)





Stress monitoring

- ability to manage timing, frequency and intensity of stress, mimicking the econditions of the TPE (Tuberosa, 2012)
- dry locations, “out-of-season” trials, delayed planting: might not reflect TPE conditions (radiation, to, VPD)
- static or moveable rainout shelters: high operating costs, limitation of number and size of experimental plots
- potted plants in greenhouses or growth chambers with robotized systems: quicker, reproducible but potted plants exposed to earlier and stronger stress (Wahbi and Sinclair 2005)

- appropriate experimental designs (Federer and Crossa 2011)
- characterization and monitoring of soil and plant water status
- genotypes with different phenologies face different stress durations (Tuberosa 2012): subsets of similar maturity, covariate adjustment
- irrigation methods (eg, drip irrigation) for better control of irrigation
- labeling of plots and samples (bar-coding), data collection and storage

Traits measurement

General Requirements

- indirect selection based on selection for "secondary traits" or plant characteristics that provide additional information about how the plant performs under a given environment (Lafitte et al. 2003)
- a secondary trait should ideally be (Edmeades et al. 1997):

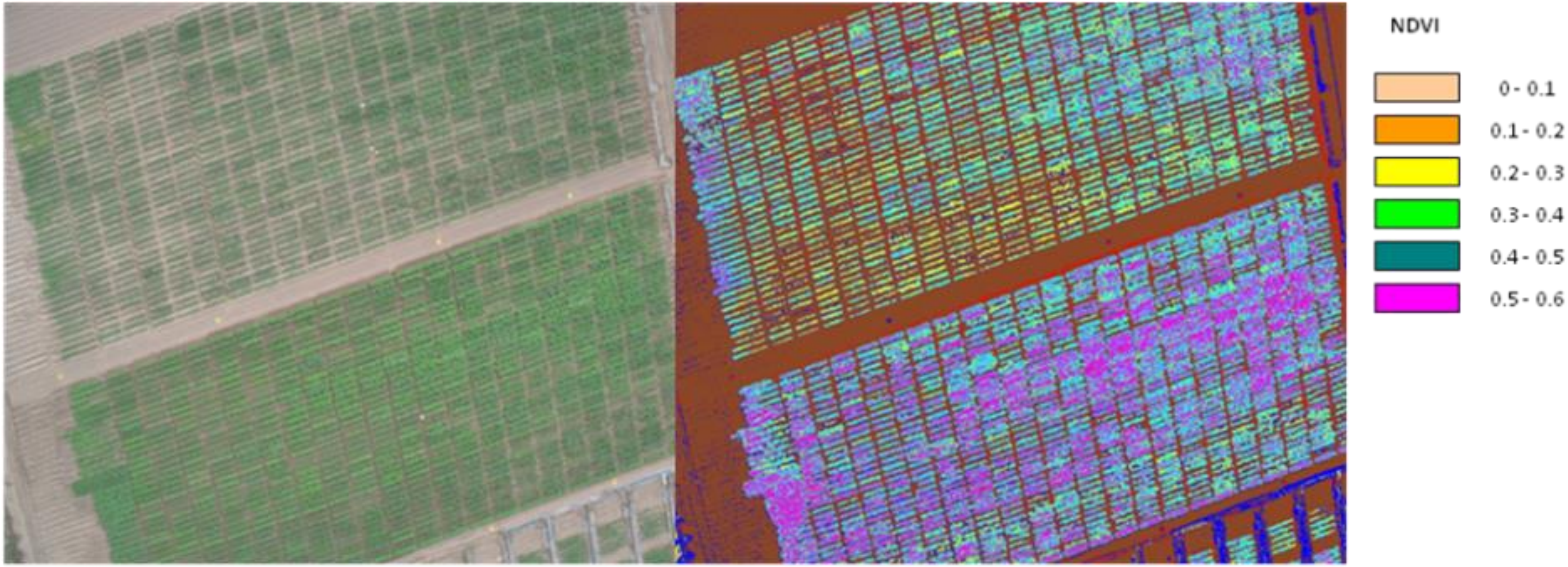
  (i) genetically associated with yield under drought; (ii) genetically variable; (iii) highly heritable; (iv) easy, inexpensive and fast to observe or measure; (v) non-destructive; (vi) stable over the measurement period; and (vii) not associated with yield loss under unstressed conditions
- the accuracy of secondary traits measurement is closely related to precision or repeatability (Tuberosa 2013)

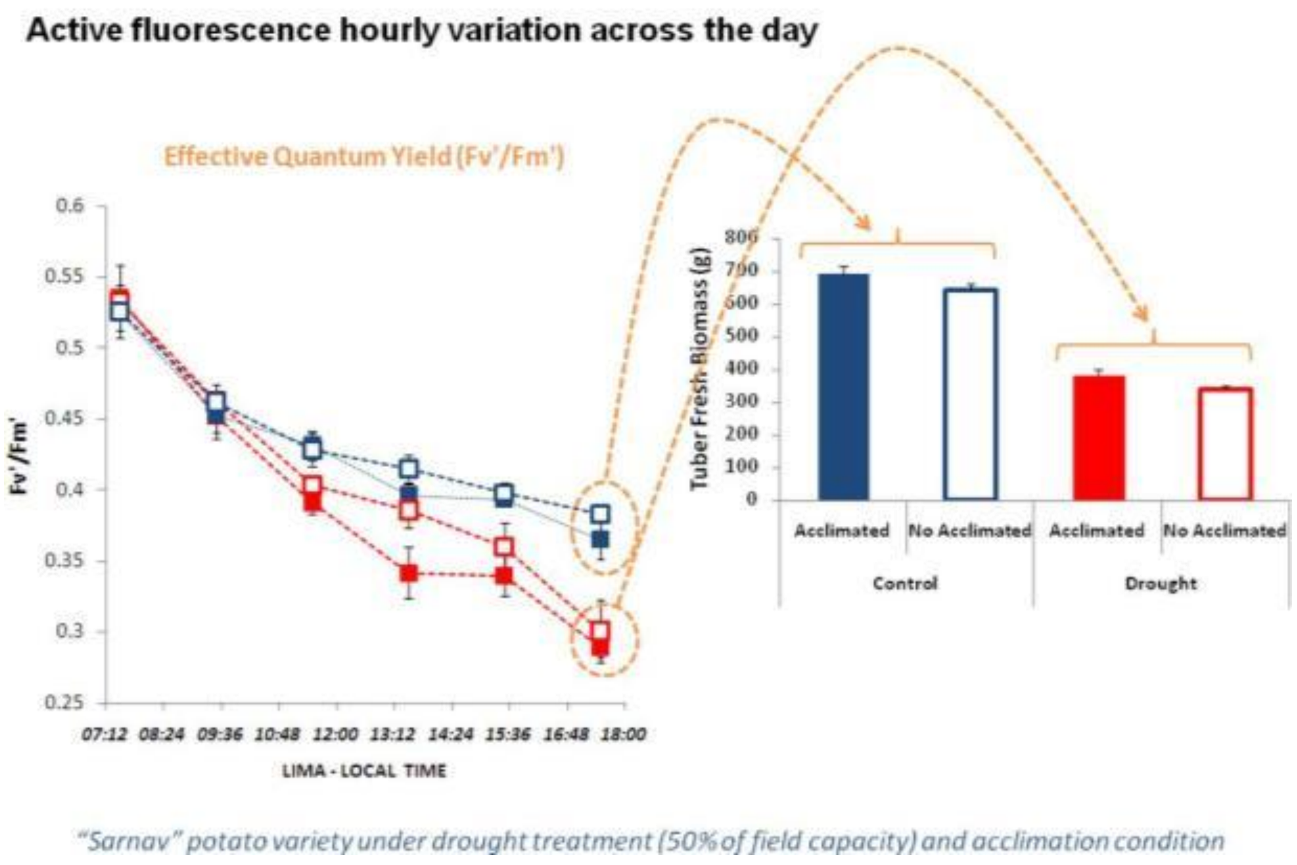
A need of more integrative measurements

- most traits are assessed through “instantaneous methods” which depend on environmental conditions during measurement
- most traits are assessed on individual plants or even on particular organs of individual plants: representativeness of the sampling
- need of traits assessment methods that are more integrative, both in time and space (Jarvis 1995)

Remote sensing

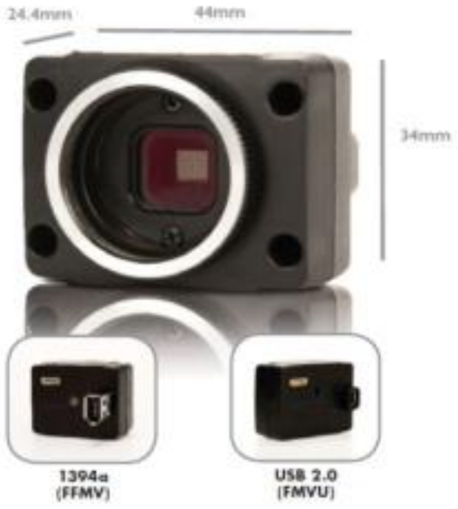
Vegetation indices based on reflectance can be used to provide information about biomass, nutritional deficiencies of nitrogen in the leaves or water stress (Peñuelas et al. 1997)





Chlorophyll fluorescence measurements reflect changes in the photochemical conversion: possibility of remotely obtaining chlorophyll fluorescence images using the discrimination method of Fraunhofer lines in the absorption bands of atmospheric oxygen (Moya et al. 1998)

To facilitate remote-sensing measurements, CIP is developing the use of unmanned aerial vehicles (UAV) transporting small and light cameras and radiometers



Thank you
for your attention!