

Practical Indicators for Sustainable Agriculture

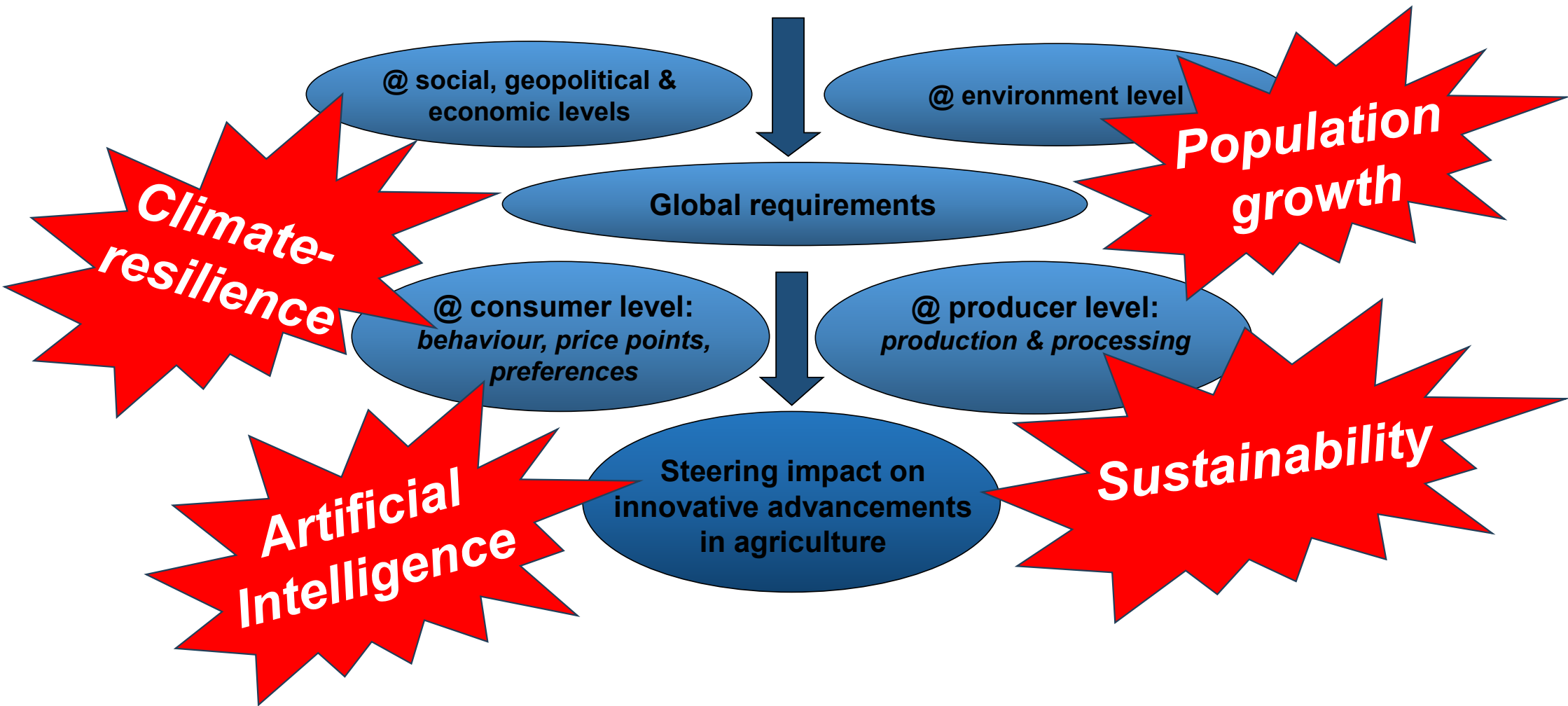
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(external)*

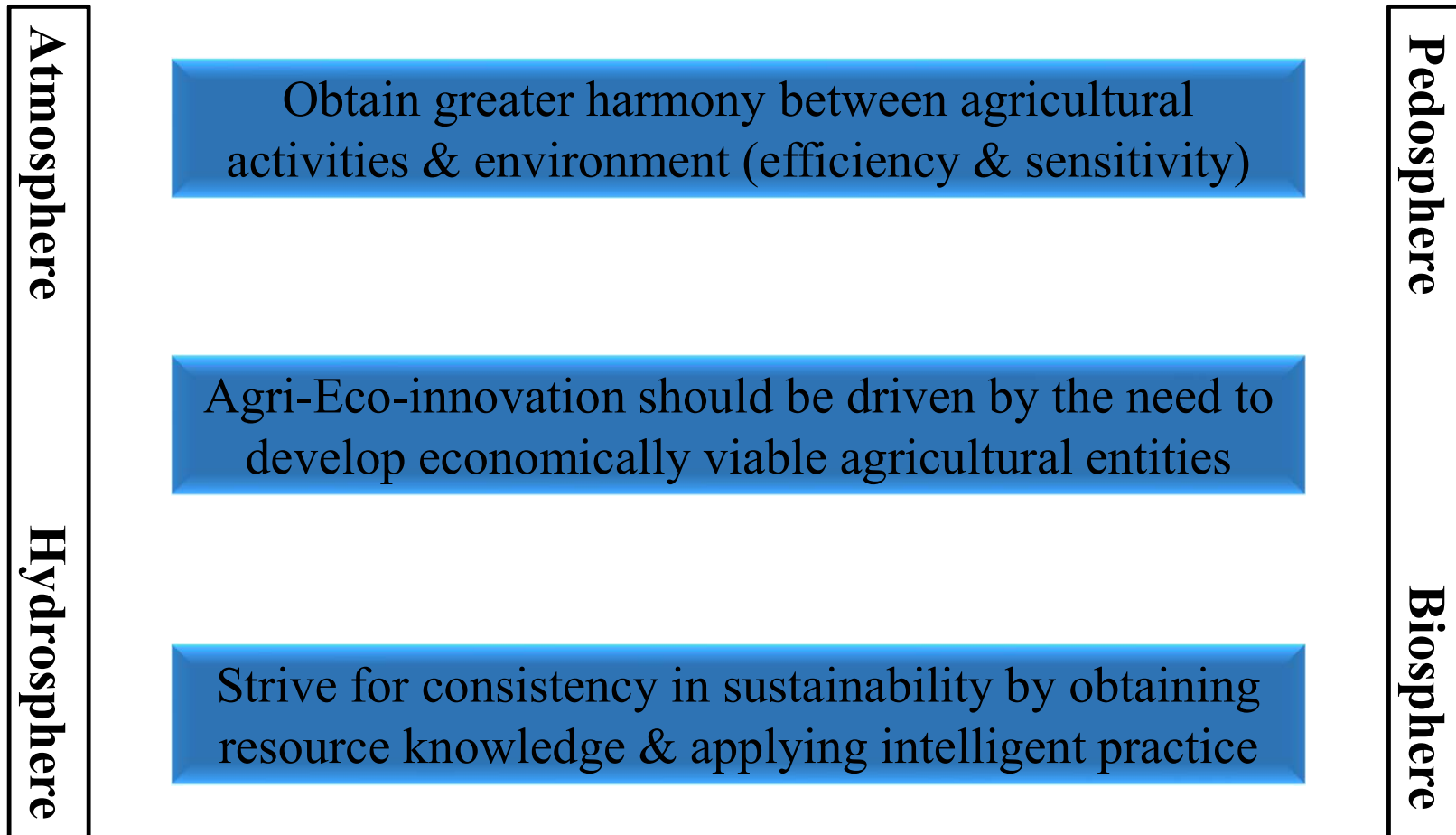
*Stellenbosch
South Africa*



Dynamic Global Movements



Alignment required at Agriculture, Environment, Ecosystem & Biodiversity levels



Sustainability

derived from Latin word *sustinere* (tenere, to hold; sus, up)

Synonyms for “sustain”: to “hold up”, “maintain”, “support” or “endure”

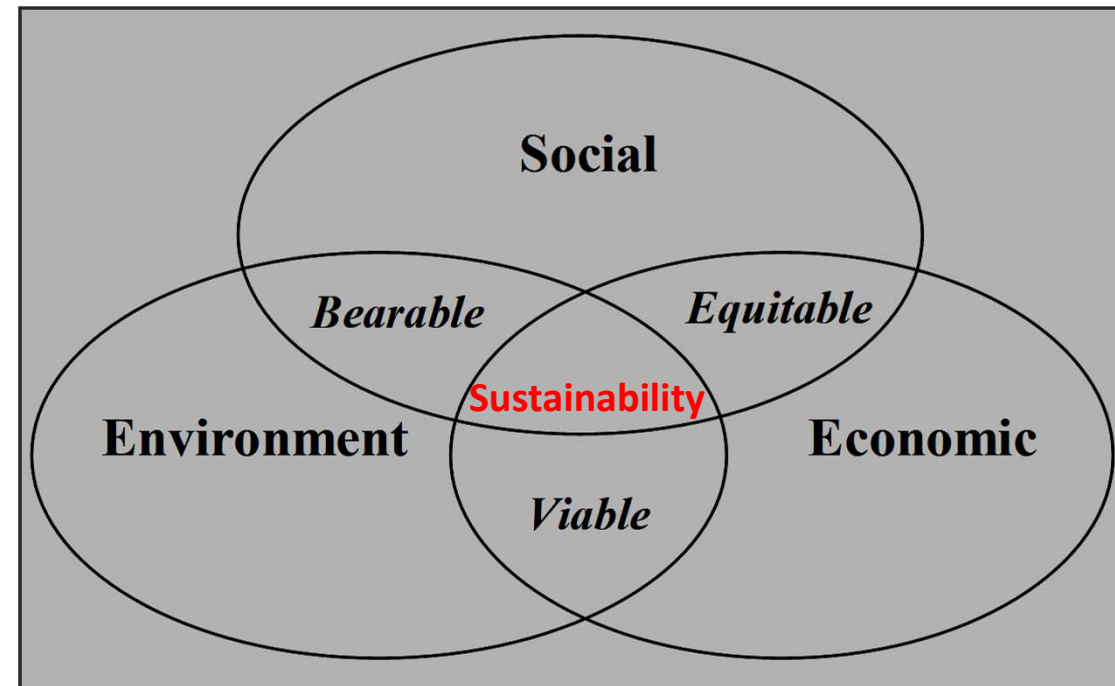
in ECOLOGY

word describes how biological systems remain diverse & productive over time, e.g. healthy wetlands & forests

for HUMANS

potential for long-term maintenance of well being, which has environmental, economic & social dimensions

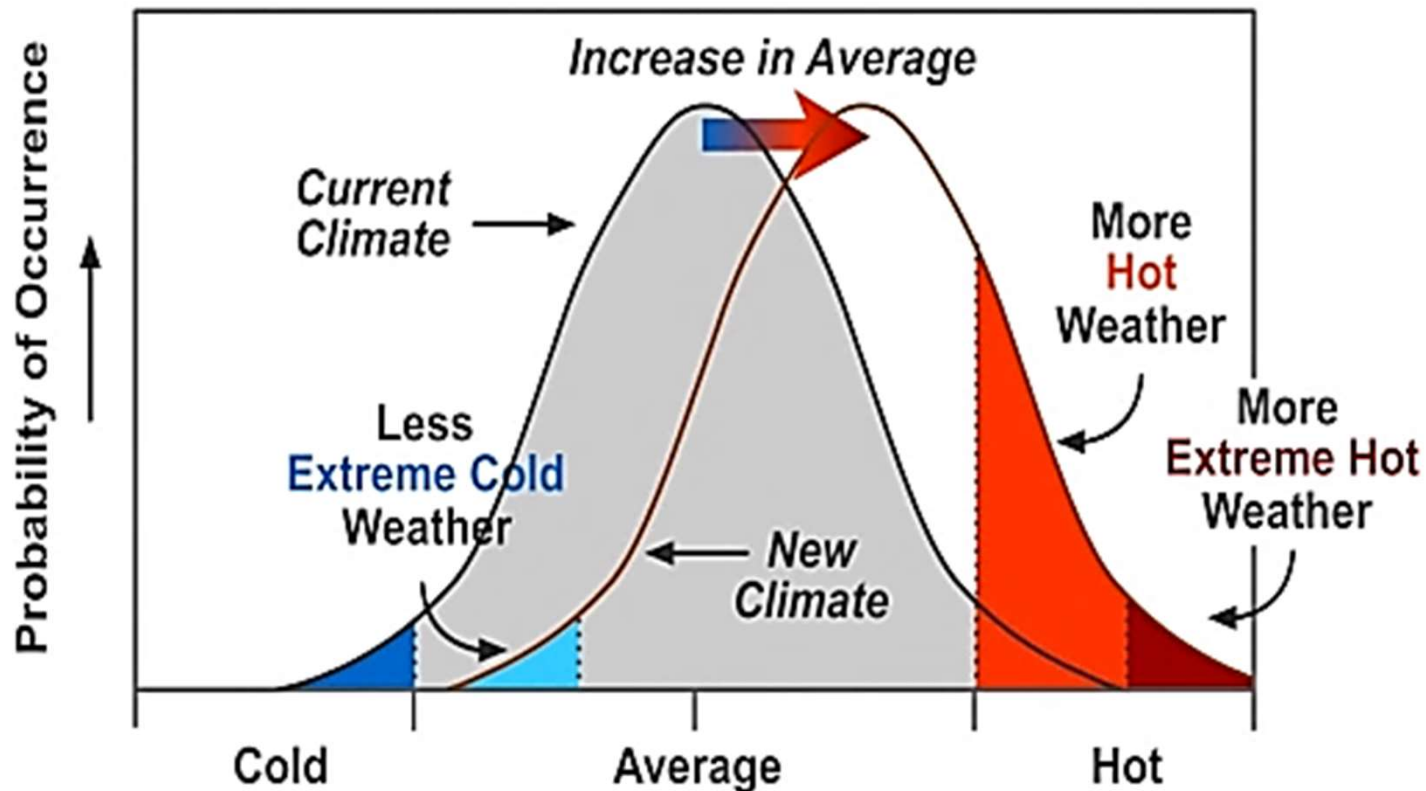
Integration of the main dimensions of “sustainability”



Adams (2006)

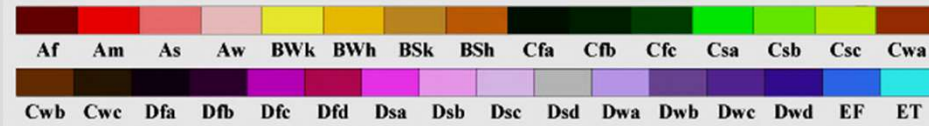
At environment level, climate change is a global factor – extremities are serious concerns for sustainability

Erratic weather, floods, droughts & heat waves: Significant implications for global food security



World Map of Köppen–Geiger Climate Classification

updated with CRU TS 2.1 temperature and VASCLimO v1.1 precipitation data 1951 to 2000



Main climates

A: equatorial
B: arid
C: warm temperate
D: snow
E: polar

Precipitation

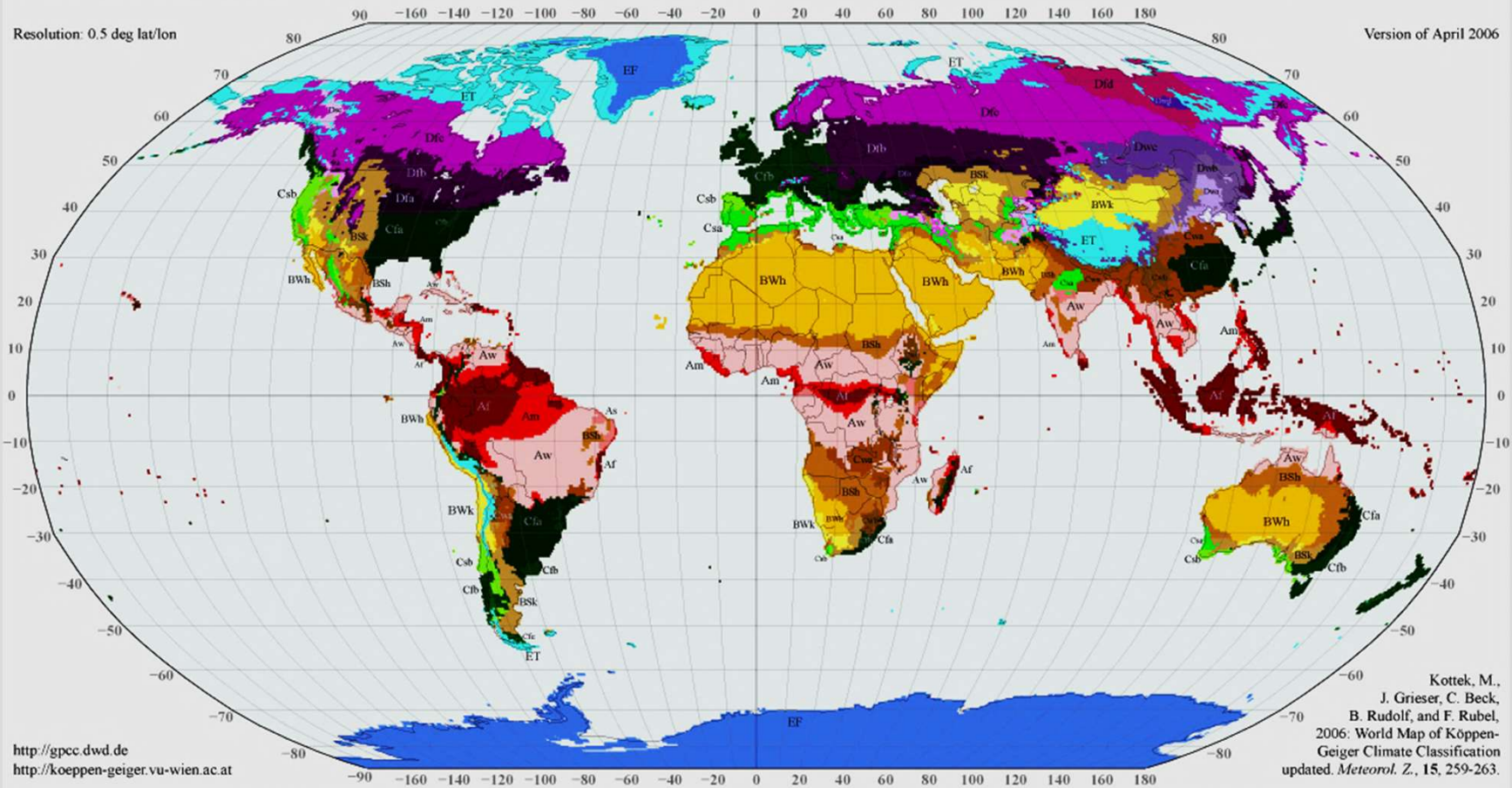
W: desert
S: steppe
f: fully humid
s: summer dry
w: winter dry
m: monsoonal

Temperature

h: hot arid
k: cold arid
a: hot summer
b: warm summer
c: cool summer
d: extremely continental
F: polar frost
T: polar tundra

Resolution: 0.5 deg lat/lon

Version of April 2006



<http://gpcc.dwd.de>
<http://koeppen-geiger.vu-wien.ac.at>

Kottek, M.,
J. Grieser, C. Beck,
B. Rudolf, and F. Rubel,
2006: World Map of Köppen–
Geiger Climate Classification
updated. *Meteorol. Z.*, 15, 259–263.

South Africa
in general

Nelspruit

Climate change impacts sustainability

Possible negative consequences

- extreme dry & wet periods - impact on plant physiological processes & disease occurrence
- high T's – challenge ranges for optimal physiological processes, e.g. Pn
- reduced availability of water supplies for agricultural use
- instable phenological events – management & logistics
- harvest date variation – yield, quality & logistics
- unpredictable fruit quality – markets & economic viability
- Inconsistency of production & quality

In arid conditions, higher T & evaporative demand may lead to desertification & salinization

- Fruit trees generally considered sensitive to very sensitive to salinity

Possible positive consequences

A gradual rise in atmospheric [CO₂] & T may lead to adaptation (may incl. epigenetic changes), e.g.:

- increased Pn rates & WUE of vegetation & crops
- increased salt tolerance
- higher soil microbial activity, that may increase
 - soil organic matter
 - infiltration rate & soil stability
 - soil resilience against erosion & nutrient loss by leaching
- **only if other factors do not become limiting**
- **especially WATER**

Sustainable agriculture for all cultivation routes

Encompassing concept – impacts all agricultural industry facets & requires a total strategy for success

Quality of plant material - physiological/morphological/disease/virus status

(impacts growth & uniformity, yield, quality, ability of crops to buffer extreme conditions)

Growth of fruit trees - variety-rootstock choices suited/matched to the environment

(identity - true to the environment; drought resistance & survival; high temperature buffer; optimal WUE/biomass production; leaf surface, roots, fruit - all important to drive metabolism)

Production

(max. use of available surface – focus on *fruitfulness* & *growth balances*)

Costs

(materials; labour wages; training & *technical skills*; storage & packing facilities)

Care of the environment, biodiversity & social aspects

Consistency of end products – consistent sustainability

(focus on product *objective*, price point, market satisfaction – be realistic in expectations from resources)

Varietal stability



At production level under field conditions

different layers of factors impact on sustainability

- climate
- soil
- cultivation practices
- required product & price point



Focus on buffering & elimination of stress factors

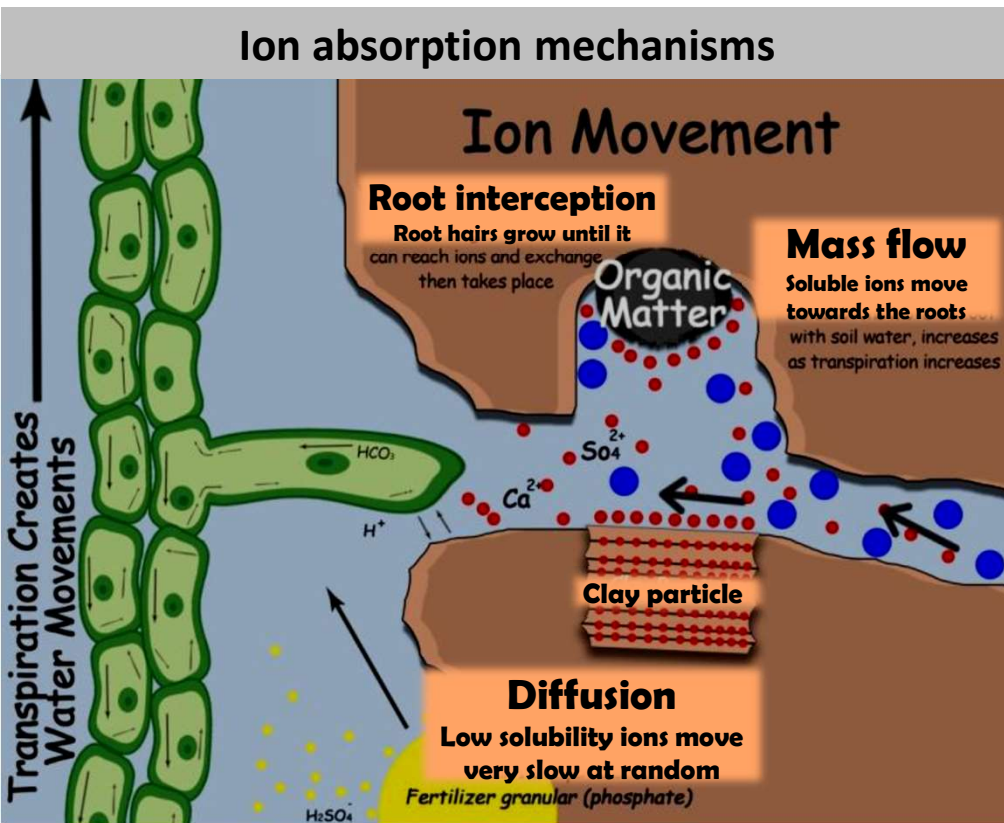
Plant resilience to the environment & biomass improvement remain critical goals

A solid foundation required for growth & production

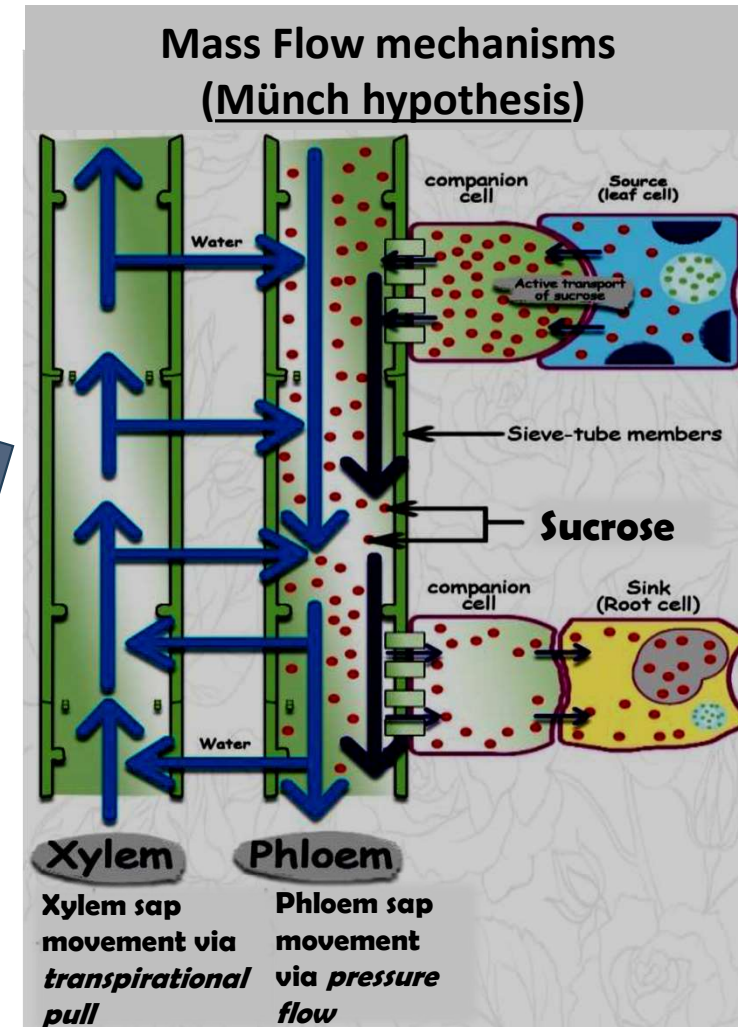
- *the more mistakes in choices & execution of practices*
- *the more stress factors that are created*
- *the more erratic crop behaviour (growth/yield/product quality)*
- ***the less potential for (consistent) sustainability & food security***

Stress factors affect functional equilibrium between leaf area & root system

- **Any soil limitation** (hard layers, compaction, water table, drought, salinity, acidity, toxic elements, mineral deficiencies, etc.):
 - decreases mineral absorption
 - restricts root development & deep root penetration
 - changes root distribution pattern & rhizosphere microbiome
 - affects the sufficiency & efficiency of the canopy to support fruit quantity & quality
- **In arid conditions**, evaporation, saline water & restrictions to drainage increase salinity



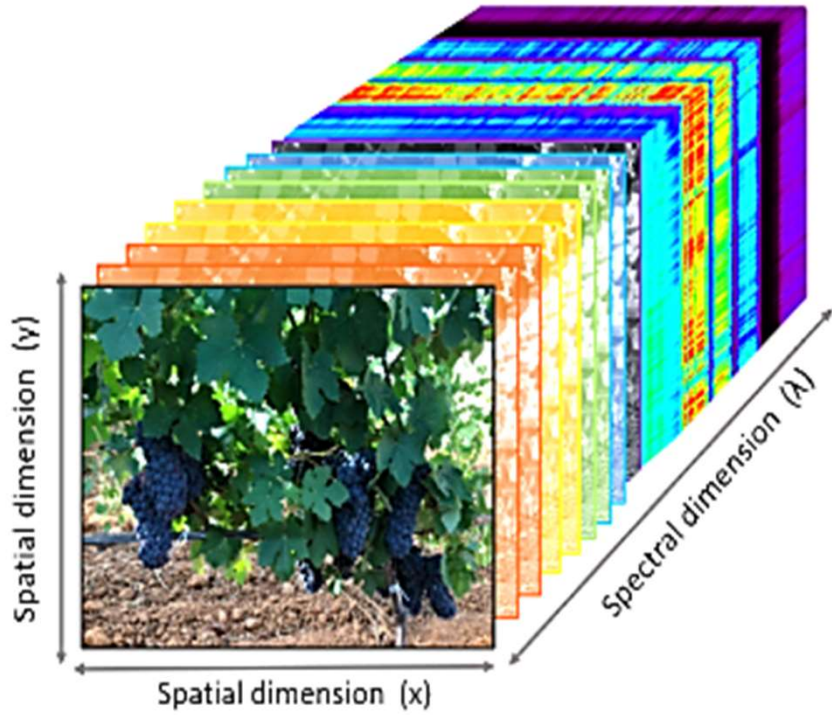
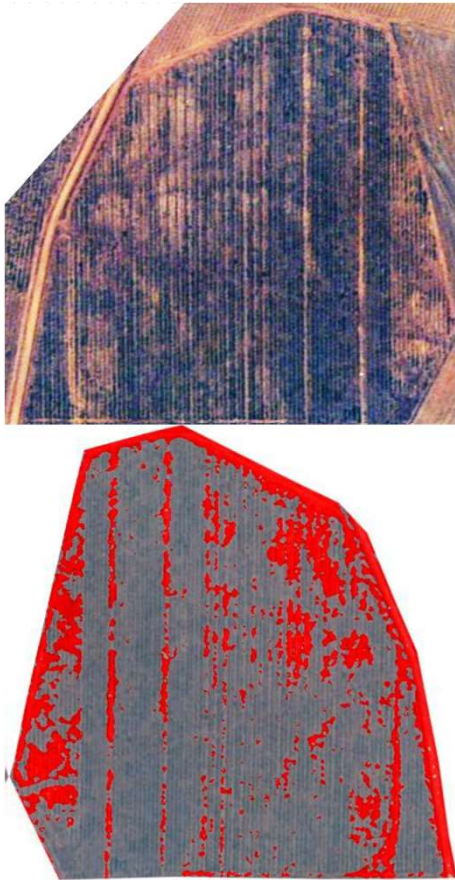
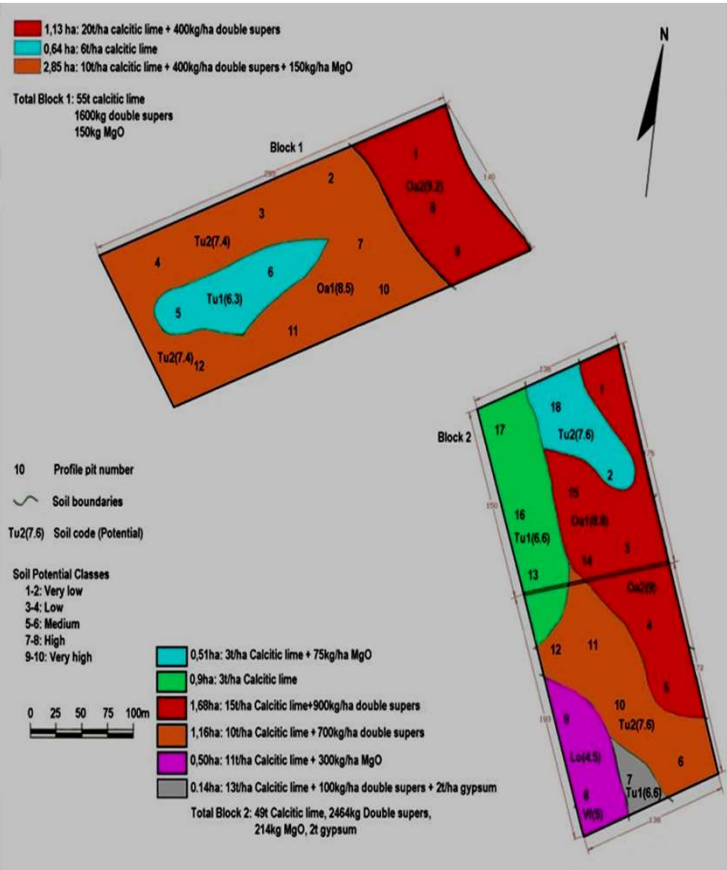
Interdependent



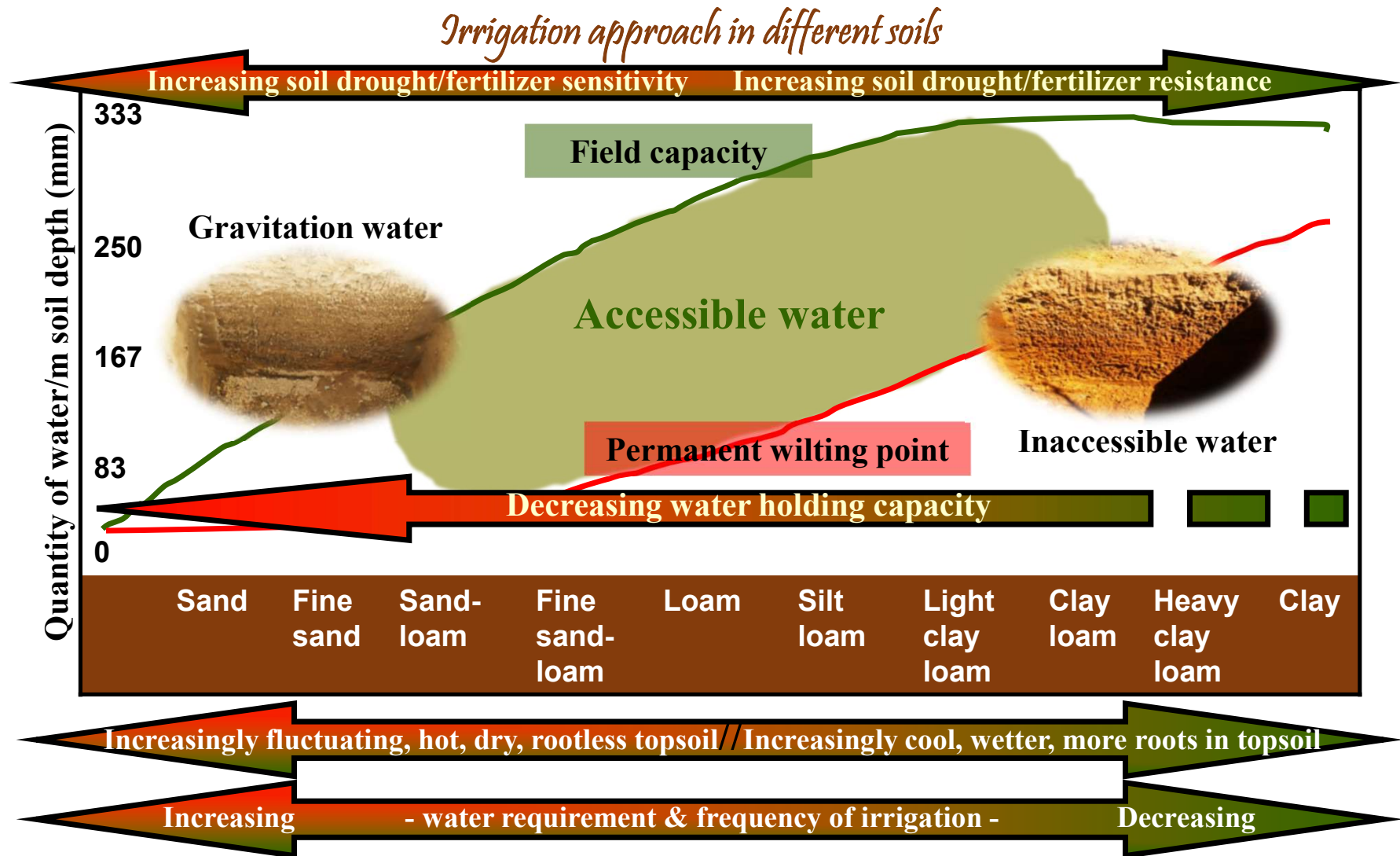
Soil & growth variation/limitations within an orchard/vineyard demarcated area is a complicating factor that affects sustainability

thorough soil type mapping & spectral response monitoring to increase uniformity & ascertain potential

Remote sensing like NDVI (Normalised Difference Vegetation Index), NIR & MIR reflectance spectroscopy, Soil pits, Soil analyses – aim to correct the soil & adapt variety/rootstock/practices to soil variation
(correlations of spectroscopy with wet chemistry low & not all elements equally well predicted, moisture interference problematic in-field)



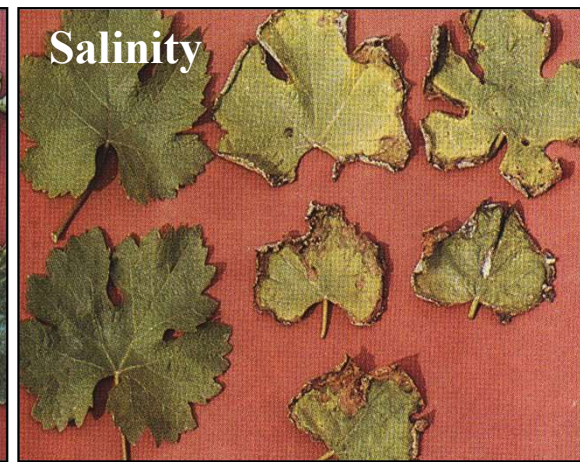
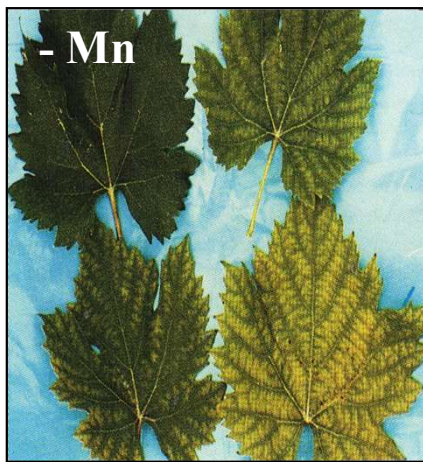
3-D hypercubes of a vineyard canopy obtained from a combination of hyperspectral & imaging techniques



the better the alleviation of soil restrictive layers & the deeper the soil preparation, the better the drought resistance & lower the frequency & volume of irrigation

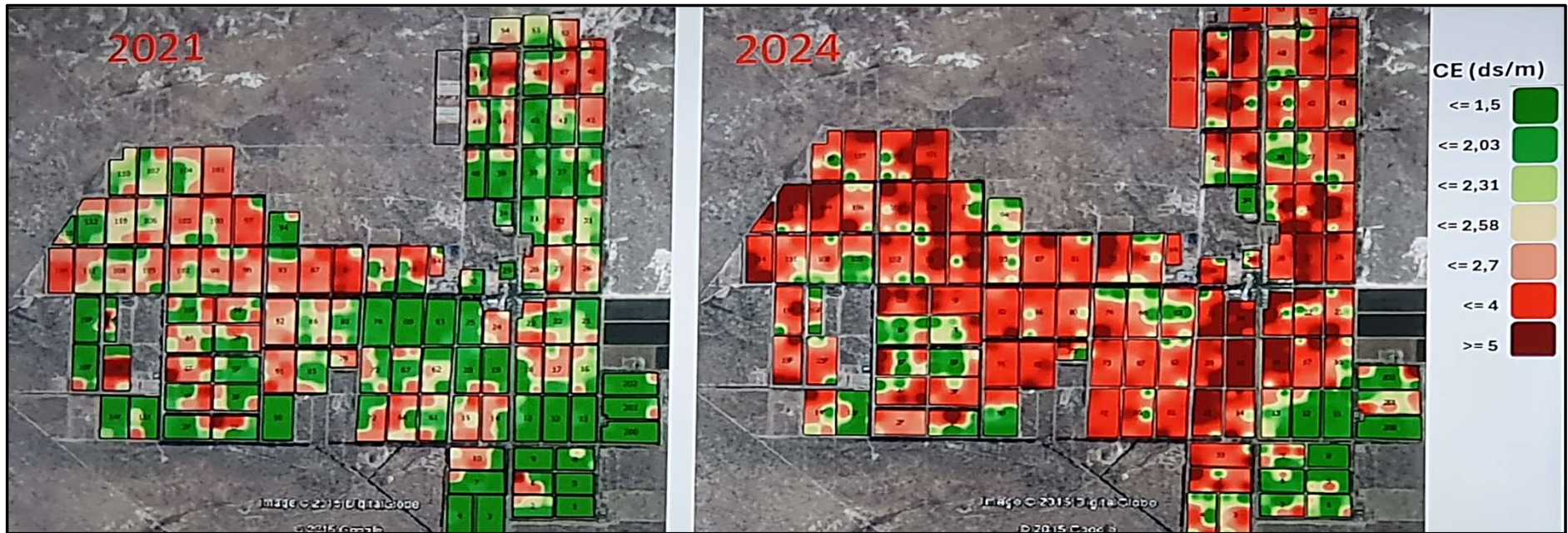
Any deficiency, toxicity or disease will impact negatively on the ability of any crop to buffer stress conditions

Pro-active regular monitoring



Electrical Conductivity Maps : 500-ha grape farm with ~ 250 mm summer rain/annum

Classification: Arid, Desert, Cold winter, High summer T, Underground water is saline (1.75 – 2.65 dS/m)



In 2021: Normal salinity 1.5 - 2.5 dS/m. In 2024: mostly 4 - > 5 ; sandy/sandy-loam soils - pH 7.1 – 7.6
(readings < 1 dS/m: soil considered non-saline – doesn't impact most crops & soil microbial processes; readings > 4 dS/m considered saline toxic – sodic)

EC_e thresholds (dS/m): Grapevines = 1.5; Apricots/Pears/Peaches/Lemons/Oranges = 1.5 - 1.7

A managing challenge with serious implications for sustainability

Salinity triggers plant physiological, soil structural (waterlogging) & microbiological (bad microbes) activities

Salinity: Under arid, saline soil & water, high T conditions



Water loss from irrigation & rooting zone
Drainage/ Transpiration/ Evaporation



Concentrates soil salt content/ increases salinity



Decreases soil osmotic status/ this slows water
absorption by roots & may even reverse it –
osmotic effect occurs before visible symptoms



Root system/Whole Plant experiences
water deficit(+?)/stress(-)



Root [ABA] increases/ Transported to aerial parts/
Stomata close/ Pn decreases/ Root absorption
decreases/ Growth decreases

Irrigation to buffer high EC & Increase crop tolerance / *Netting* to buffer evaporation, high T & hail

Flood & Drip irrigation for Salinity & Growth control

Focus on:

- Improving soil mineral balances (focus on P & K – decrease N:K ratio), organic matter & resilience – compost, mulch & cover crops (Thresholds of Rye = 5 - 11 dS/m; Triticale = 6 dS/m; Vetch = 3 dS/m)
- Variety & rootstock tolerance to salinity
- Drippers – closer & higher volumes – frequency unchanged – install deep drainage if possible (irrigate beyond crop evapotranspiration requirement)
- Zn sprays – stimulate Pn activity; B sprays – stimulate root activity & fruit set
- **In practice, water stress still more damaging under high T & saline conditions than salt stress**



Rootstock properties

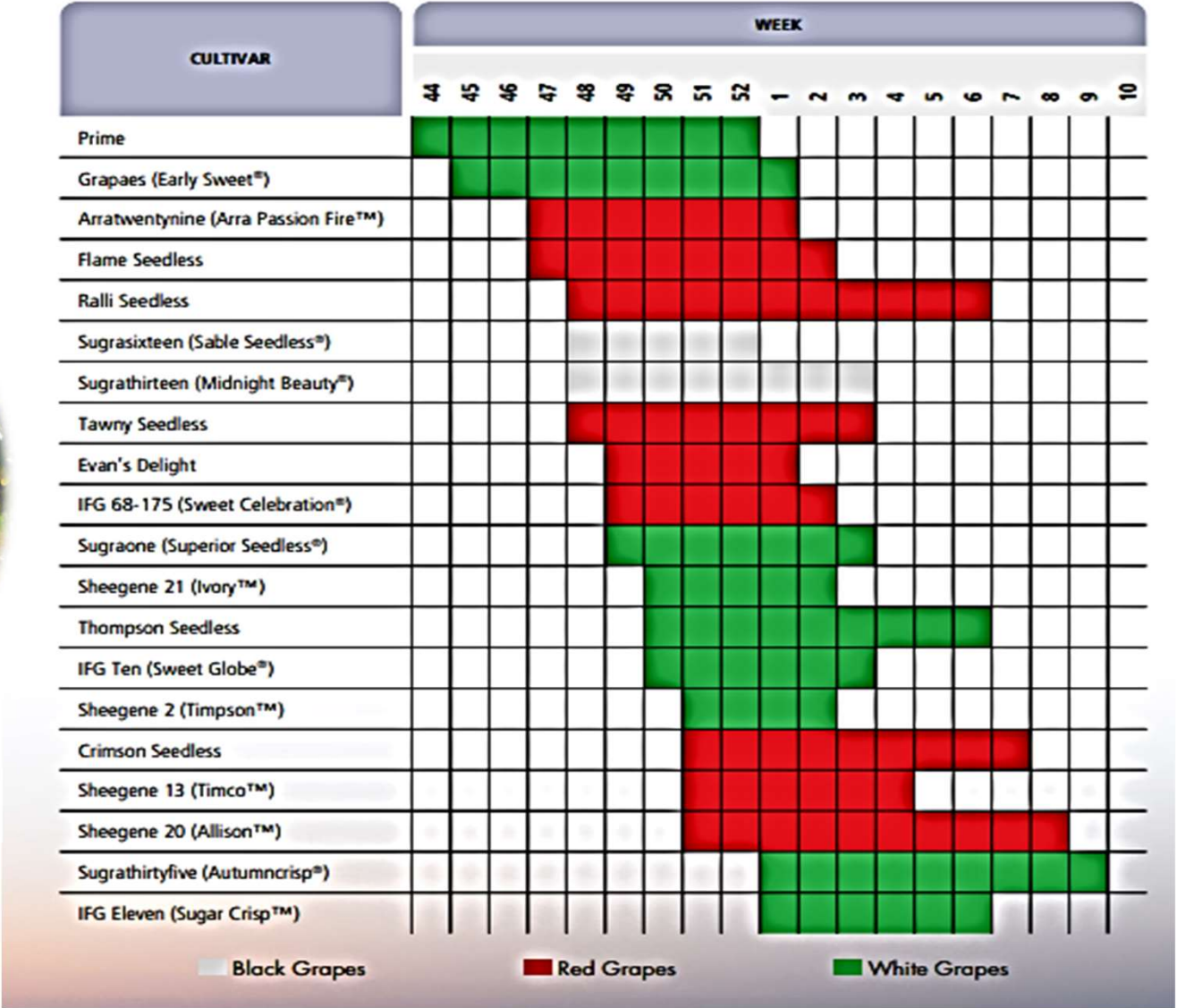
According to soil type & soil borne pests

Rootstock	Affinity	Vigour	Phylloxera	Nematodes	Phytophthora	Lime	Salinity	Wetness	Drought
99 Richter (<i>V Berlandieri</i> x <i>V rupestris</i>)	A	A	1	2	4	B	B	C	B
110 Richter (<i>V Berlandieri</i> x <i>V rupestris</i>)	A	A	1	2	3	B	B	B	A
101-14 Mgt (<i>V riparia</i> x <i>V rupestris</i>)	C	B	2	2	2	D	A	A	C
420-A Mgt (<i>V Berlandieri</i> x <i>V riparia</i>)	B	B	3	3	2	D	D	C	B
143-B Mgt (<i>V vinifera</i> x <i>V riparia</i>)	B	A	2	2	1	C	B	A	B
Jacquez (<i>V aestivalis</i> x <i>V cinerea</i> x <i>V vinifera</i>)	A	B	4	4	1	B	C	B	C
775 Paulsen (<i>V Berlandieri</i> x <i>V rupestris</i>)	C	A	1	2	1	B	B	B	A
1045 Paulsen (<i>V Berlandieri</i> x <i>V rupestris</i>)	C	B	1	2	2	B	B	B	B
1103 Paulsen (<i>V Berlandieri</i> x <i>V rupestris</i>)	A	A	1	2	4	B	C	B	A
3306 Couderc (<i>V riparia</i> x <i>V rupestris</i>)	C	B	2	3	4	B	D	B	C
3309 Couderc (<i>V riparia</i> x <i>V rupestris</i>)	B	B	1	2	3	B	D	C	D
140 Ruggeri (<i>V Berlandieri</i> x <i>V rupestris</i>)	A	A	2	3	3	A	B	C	A
SO4 (<i>V Berlandieri</i> x <i>V riparia</i>) x <i>V riparia</i>	B	B	2	2	4	C	D	B	D
Rupestris du Lot (<i>V Berlandieri</i> x <i>V rupestris</i>)	C	A	1	1	4	B	B	B	B

A=Excellent; B=Good; C=Fair; D=Poor; 1=Resistant; 2=Moderately resistant; 3=Moderately susceptible; 4=Susceptible

Table grape properties

According to climate suitability & market access



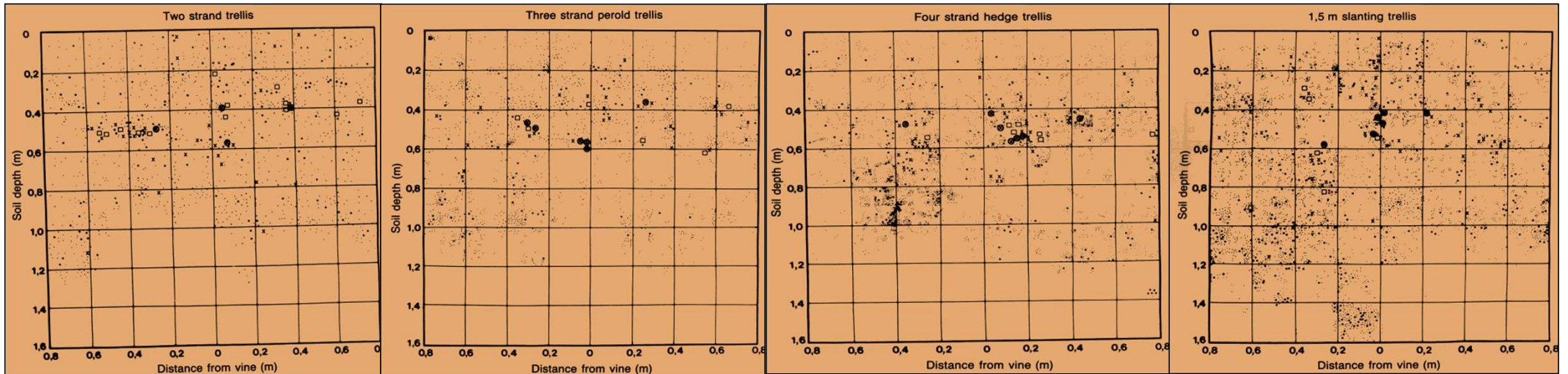
Canopy has physically protective & metabolic roles: driving factors for yield & quality
challenging for trellising & pruning



Grapevine trellis/size effect on root development & distribution

Trellising system	Shoot mass:Crop mass ratio	Soil depth (cm) & Root number									
		0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	Total	Fine roots (<0.5 mm)
2-Strand Hedge	0.25	180	285	223	175	224	94	27	0	1208	1010
3-Strand Hedge	0.25	235	398	374	124	317	184	6	0	1638	1494
4-Strand Hedge	0.22	266	465	780	517	464	351	28	0	2871	2606
1.5m Slanting	0.20	439	687	569	577	716	604	179	173	3944	3482

Bulk density (kg/m^3); 0-40 cm = 1871; 40-80 cm = 1687; 80-120 cm = 1555

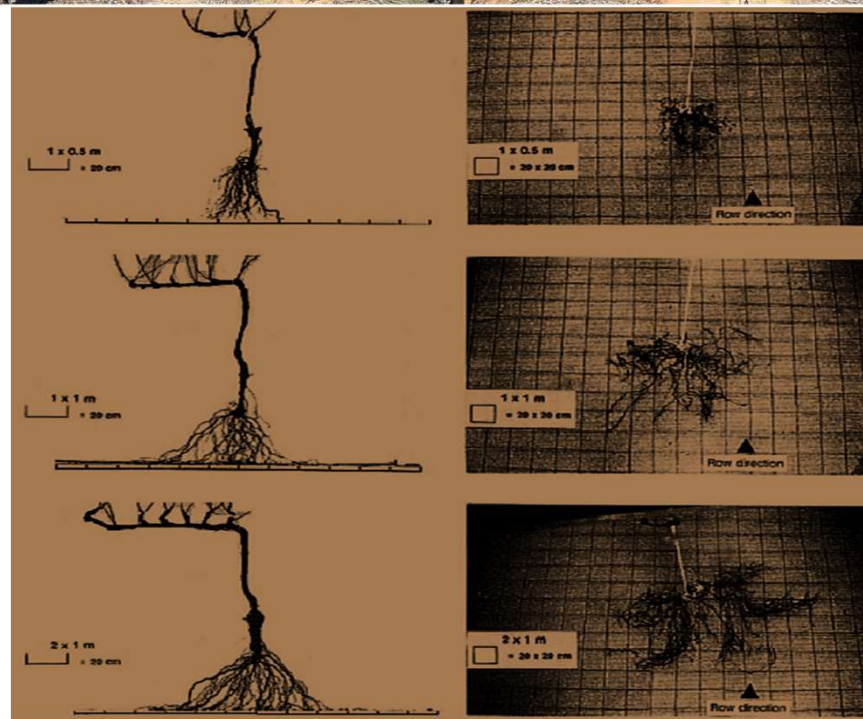


Grapevine spacing – principle: max shoot/bunch number/ha – significant effects on growth balances

1 000 – 15 000
vines/ha



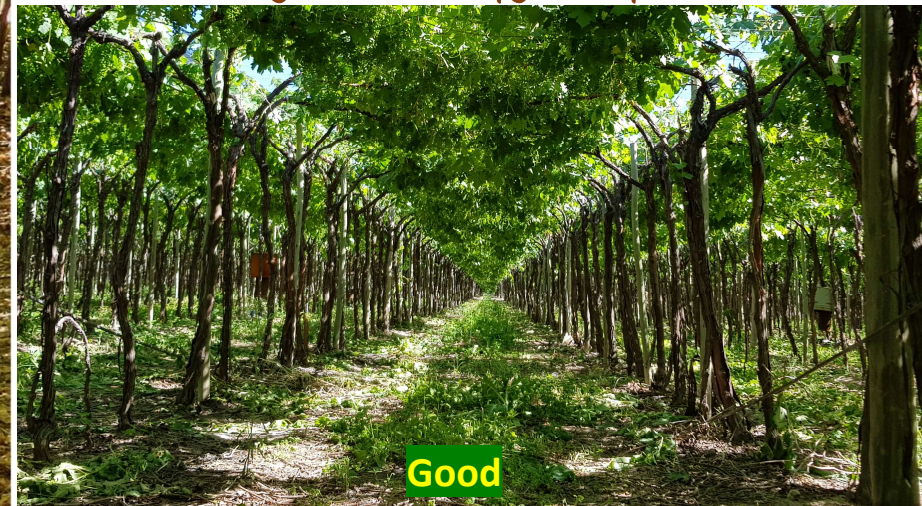
1 000 – 20 000
vines/ha



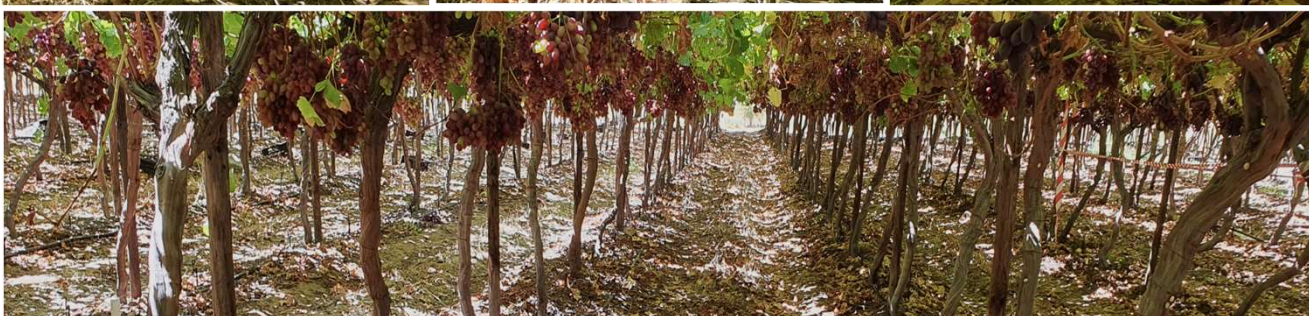
What effects spacing?
e.g.
Soil type
Soil depth
Water availability
Variety/rootstock graft
Climate
Disease occurrence
Practical considerations



Irrigation & Canopy development



Cluster thinning





Sufficient & efficient canopies and root systems to mitigate extreme conditions & increase sustainability
variety-orientated evaluations focused on best practice, environment suitability & productivity – increase consistency of yield/quality



Grapevine Minimal/Spur/Mechanical pruning



Sustainability at production & quality level requires
Solid foundation of long-term practices (planting!!)
Comprehensive seasonal practice strategy

Focus on maintaining fertility:
Sunlight penetration critical
(pruning, spacing, growth-fruit balances)

Poor planting, poor growth, deficiencies



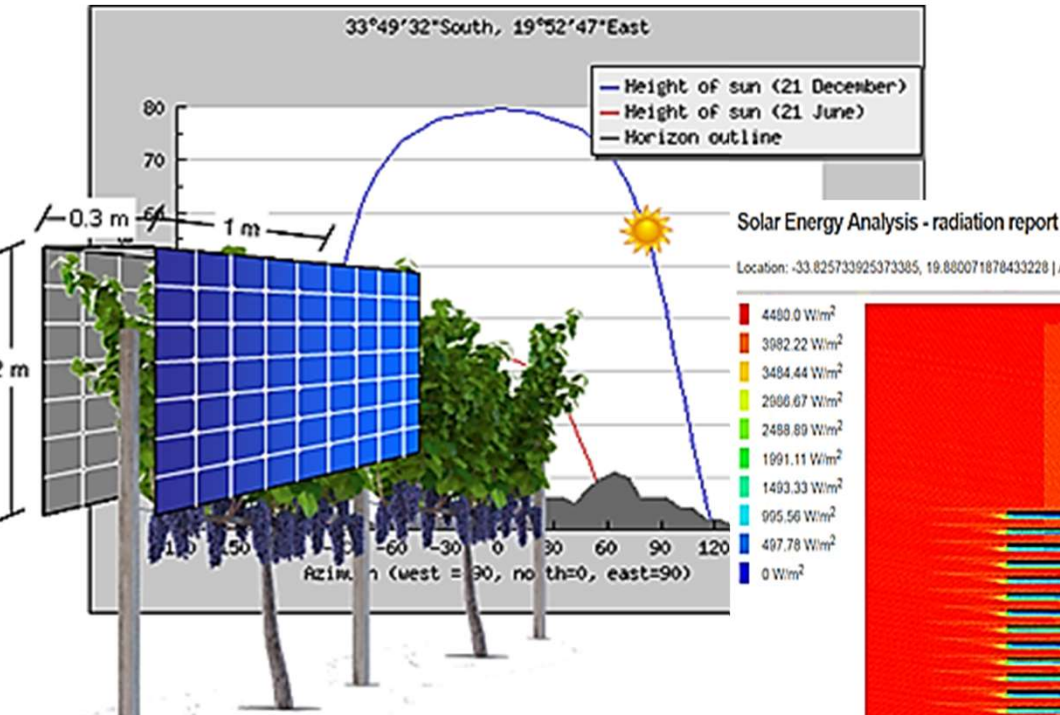
Citrus
Canopies
Root distribution



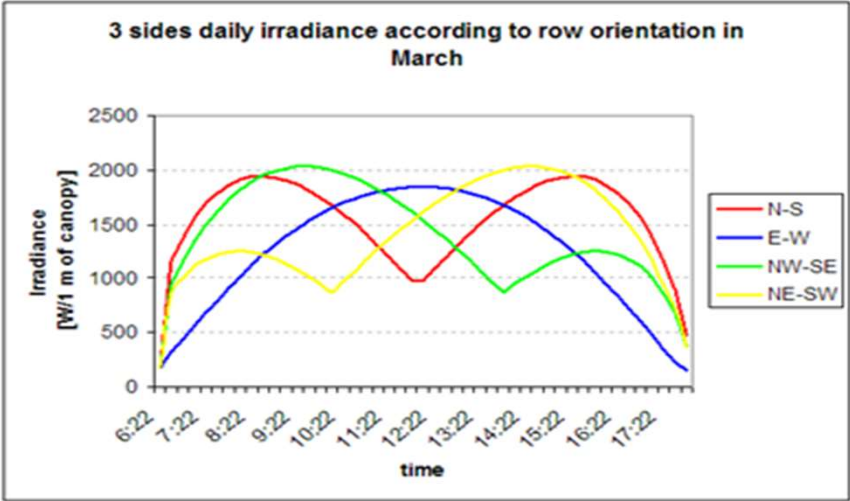
Solar Energy Mapping

Grapevine canopy orientation: Total calculated (PVGIS) energy (kW/m) onto the three surfaces of linear canopy (both sides = 4.3 m²):

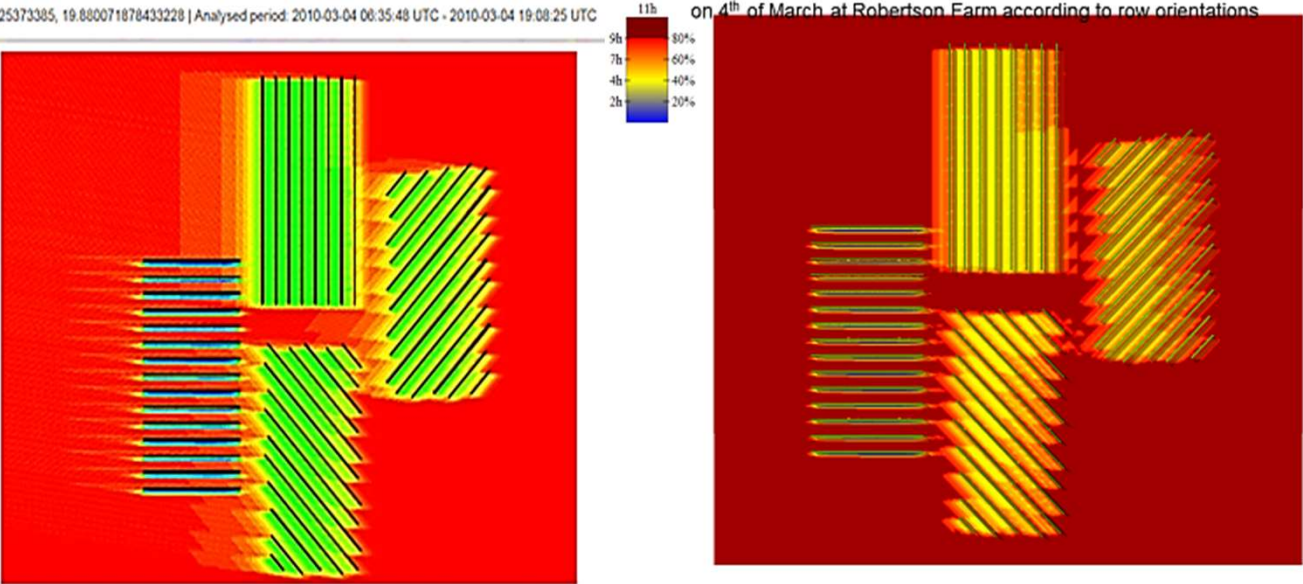
NS = 72 ; NW-SE = 65 ; NE-SW = 65 ; EW = 56



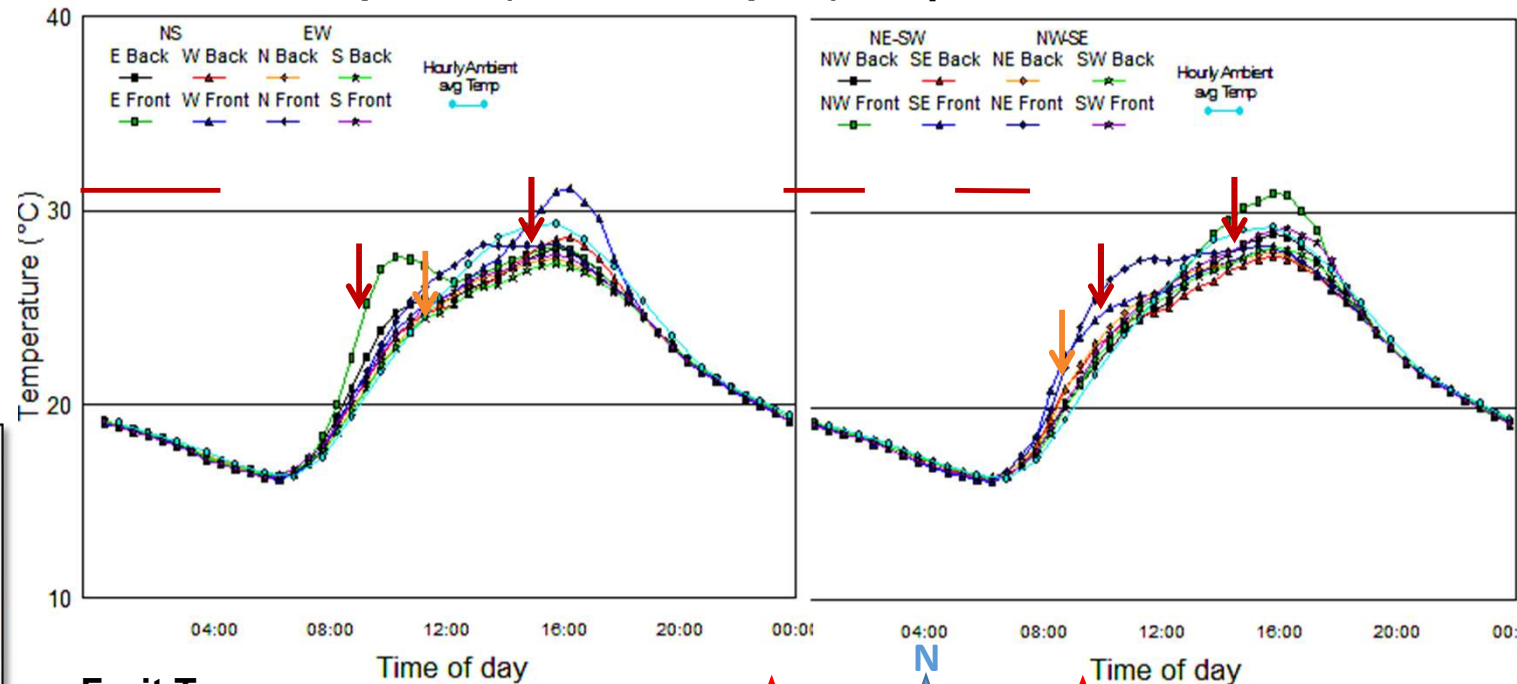
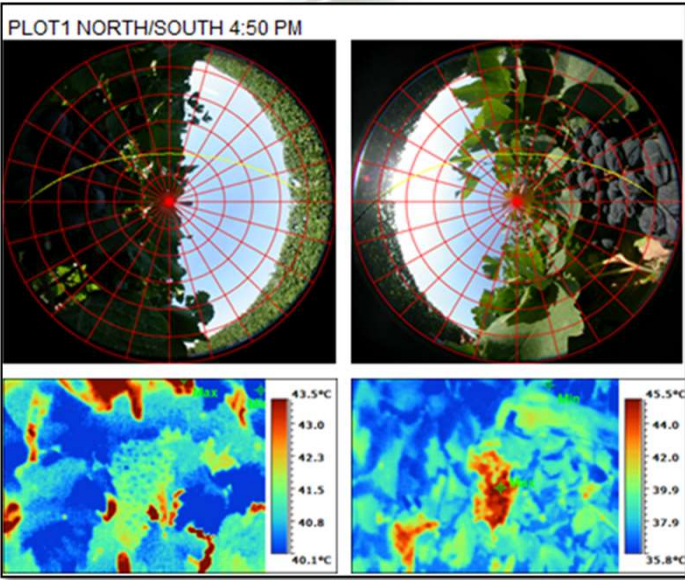
Every leaf is a “solar panel”



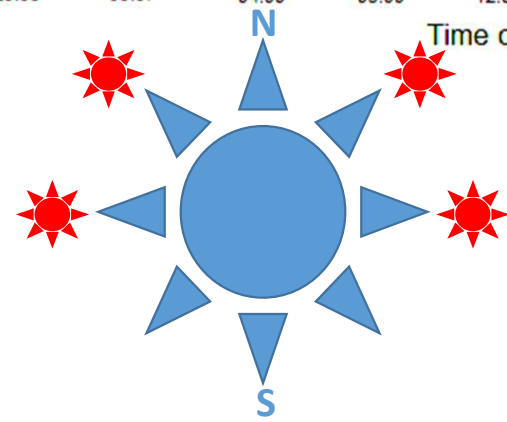
Sunhours calculated with the SunHours Plugin for Sketchup Make 2017 on 4th of March at Robertson Farm according to row orientations



Sensor technology & Imaging: Average seasonal (from pre-véraison to harvest) day/night T profiles of exterior-& interior-canopy-facing berries over a 24-hour period (thermo-couples) - *impact of direct radiation*



Fruit T
↓
Fruit metabolism, growth & composition
↓
Fruit taste
Fruit flavour



Innovations

Advancing maturation or Delaying harvest

(Also protection – rain, hail, frost, wind, heat waves – to increase control over microclimate, growth, fruit composition – various netting & plastic covering materials)

- **Advancing berry ripening**
 - *Winter covering* advances budburst
 - Advance 10 - 40 days
- **Delaying cluster harvest**
 - *Véraison covering* delays ripening
 - Delay max. 90 days
- **Creates a protective growth environment**
 - increases CO₂ consumption, berry size & uniformity
 - reduces diseases & chemical sprays

High T & Sunburn on leaves under plastic are risks



Vineyard covering with transparent plastic film

Open Field Production



Plastic covering before budbreak – greenhouse - early production



Plastic covering after véraison – late production



- Enlarging grape marketing spectrum
- Multiple annual production out of season – 2nd cycle after cold storage of vines
- Quick introduction of new varieties
- Easy management
- Inside or Outside cultivation
- Environmental sustainability – recycling
- Yields: /plant = 2 - 3.5 kg; 10 - 20% bigger clusters & berries
- Issues: High air T, low Hum, High VPD – Solutions - Windows & Fog systems
- **Soilless Vertical Farming is an option**

Soilless cultivation



High-Tech Smart vertical & horizontal greenhouse farming

Suitable for small & non-arable land surfaces

ideally having abundance of sunshine to create (solar-based) green energy for heating, cooling, lighting, irrigation, recycling, monitoring, E conveyers & EV transport...

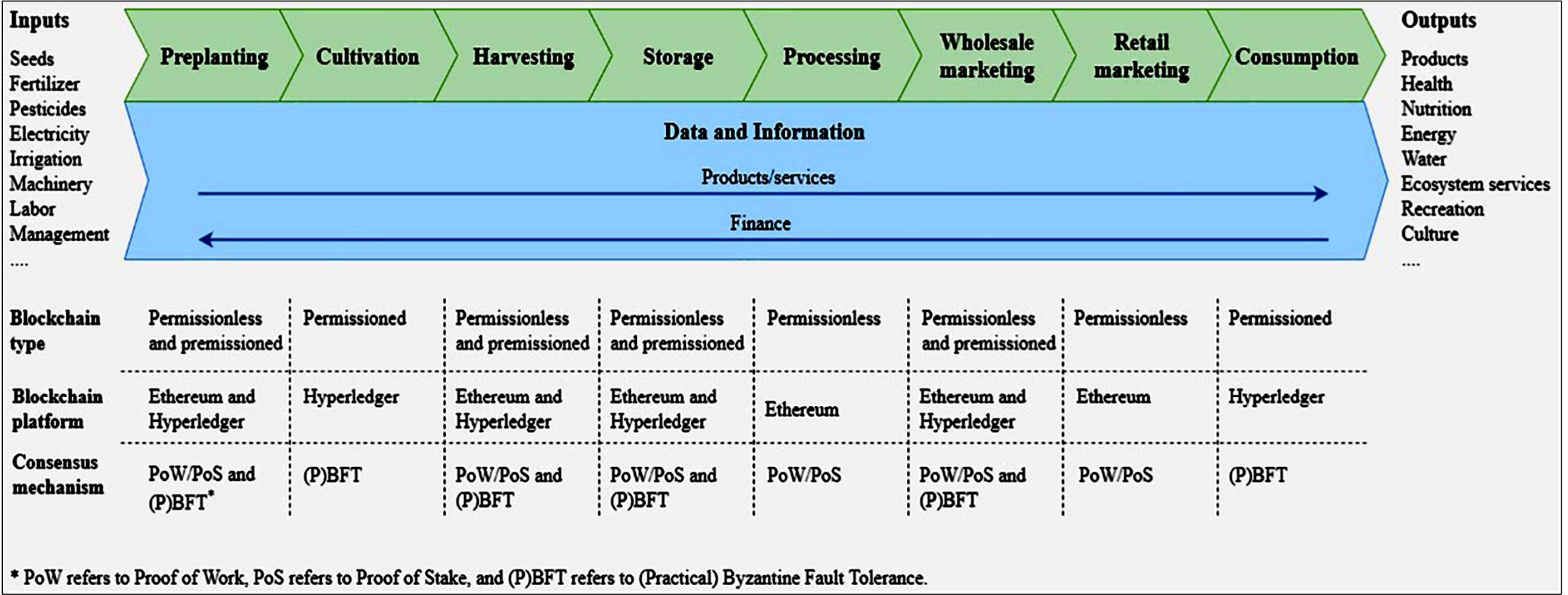


Modern e-AgriTech Innovations

**tools to enhance
resilient, efficient &
sustainable Agri-
practices for future
food security**

- **Breeding** – focus on specific climate resilient traits, using bioinformatics to manage genomic & phenomic data, speed breeding & field acclimation
- **Precision smart-phone linked remote-sensing farming by satellite, drone & robotic imaging** for precision management to obtain uniformity in soil, growth & fruit development – data driven approach – drones have application in many ways, e.g., spraying of orchards
- **Automated smart irrigation** – monitoring & metering, weather stations & field synchronization, optimized water use per soil & variety
- **Sensor & GPS technology** – leaf & soil sampling, precision fertilizer application & fungicide/pesticide spraying, vegetative & reproductive growth monitoring, fruit tracing after harvest – to reverse optimize
- **Spectroscopic HSI** in visible-near infrared (VNIR) & short-wave infrared (SWIR) regions & **Thermal imaging** provides spectral & spatial data – strives to determine & predict plant water stress (related to leaf T), fruit freshness & ripeness level – in development
- **Machine vision scanning** used for fruit sorting (size & colour)
- **Data-driven technology – big data integration** and inter-communication in a single platform for accurate analysis, predictive analytics & informed decision-making
- **Blockchain technology** – consortium, private & public models – to generate records, tracking, tracing & logistics for smart farming, information/data-linked production risk reduction, technology-based insurance compensation, insurance solutions, supply & transacting of products – checks & balances and transparency in whole food supply chain to improve trust between producers & consumers in the Agri-food market re quality, safety, and environment-friendly production of products – major investment required for full e-based operation
- **Investment in Information & Communication Technology (ICT)** – to benefit crop yield, quality, cost-efficiency, sustainability & trustworthiness – has potential to boost profitability, stimulate rural development & create employment opportunities

Blockchain data & information flow along the food value chain (Xiong et al., 2020)



None of this possible without crop-specific knowledge & practices

Challenges
to e-AgriTech
adoption

- **Possibility @ ground level** for the average farmer to obtain & afford such sophisticated communication, equipment & data collection and storage abilities – is ownership cost-effective & wise for all – aspiration-driven implementation?
- **Barriers** – geo-political, financial, technical, infrastructural, and regulatory, but also crop-specific data & enhances – human comprehension & application remain key
- **Strategies to promote** widespread implementation of e-AgriTech may be delayed - generational gaps
- **Needs of the plant foremost** – no innovative agricultural route or practice will be completely successful without a solid knowledge foundation focused on specific crop cultivation requirements
- **Basic, good practice** simplifies the need & enhance the efficiency of any smart technology intervention
- **Both human inputs & AI required** to manage & integrate practical challenges for sustainability – there is a place for everyone in agriculture – it's multi-faceted

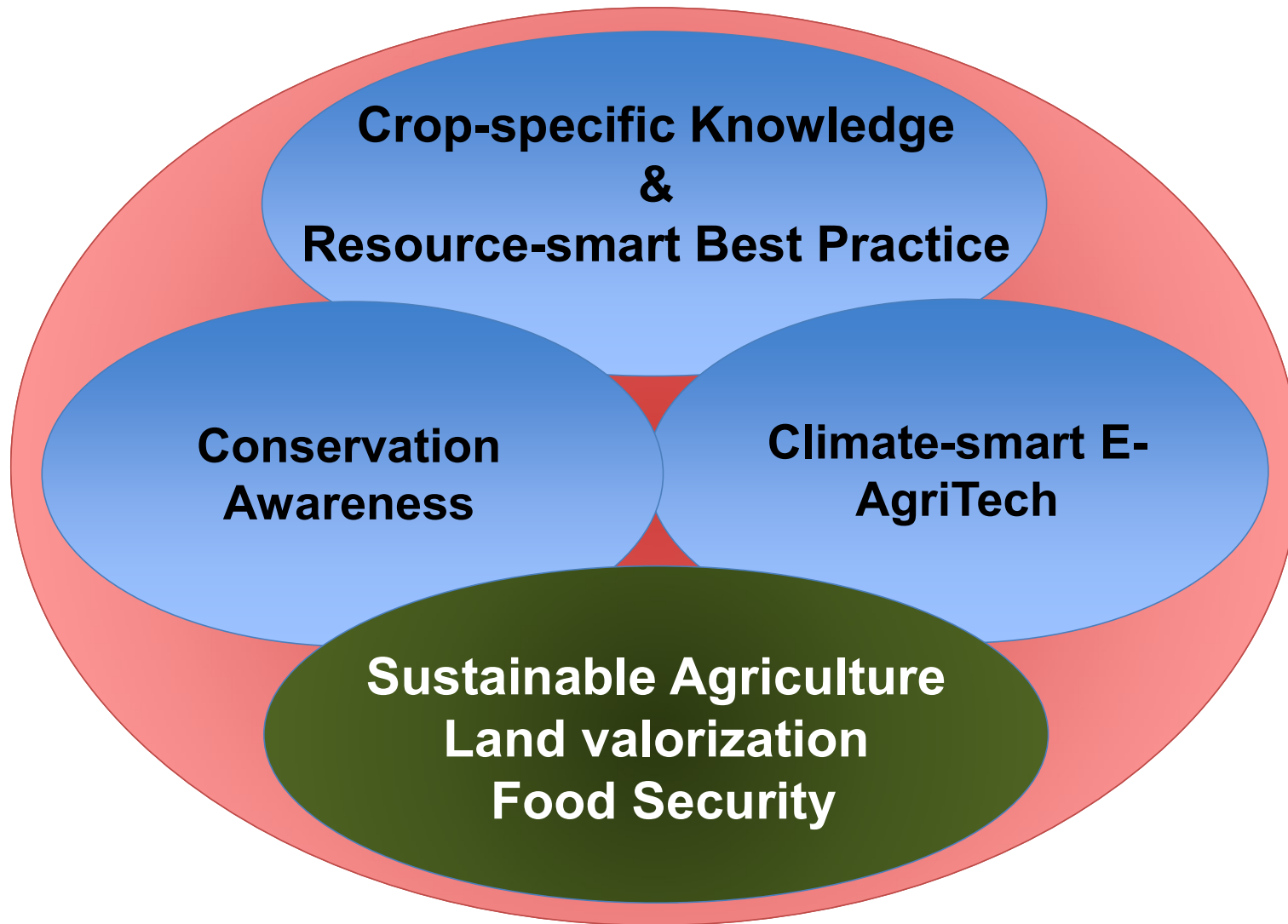
Digital agriculture can potentially influence society by increasing:

- Economic efficiency
- Equity – inclusion of smallholders
- Environmental sustainability – reduce carbon footprint, reduce food waste, recycle waste, improve resource management, promote precision environment-friendly practices
- Food security

Communication, Integration & Data-sharing of platforms are the glue & key to success



At farm level



Thank you