Improvement of climate suitability model for fruit trees

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Climate change

Climate change would cause **increase in temperature**, **variations in rainfall**, and increase in frequency of **extreme events**

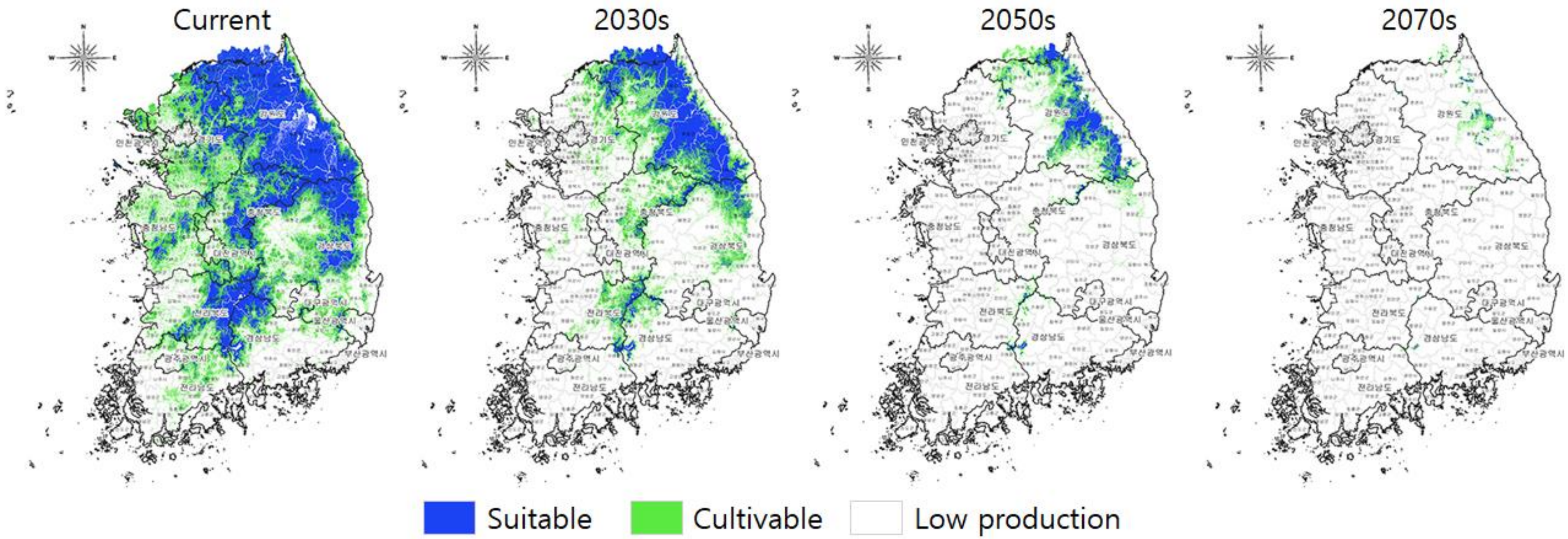
Impacts of climate change on crop growth

- Increase in **respiration** and change in **photosynthesis**
- Change in timing of **flowering** and **maturity**
- Reduction in **quality**
- Reduction of **winter chill** for the plants use the dormancy mechanism

Shift in cultivation area

Identifying suitable sites is of primary importance

Fruit crops require heavy investment to establish orchards



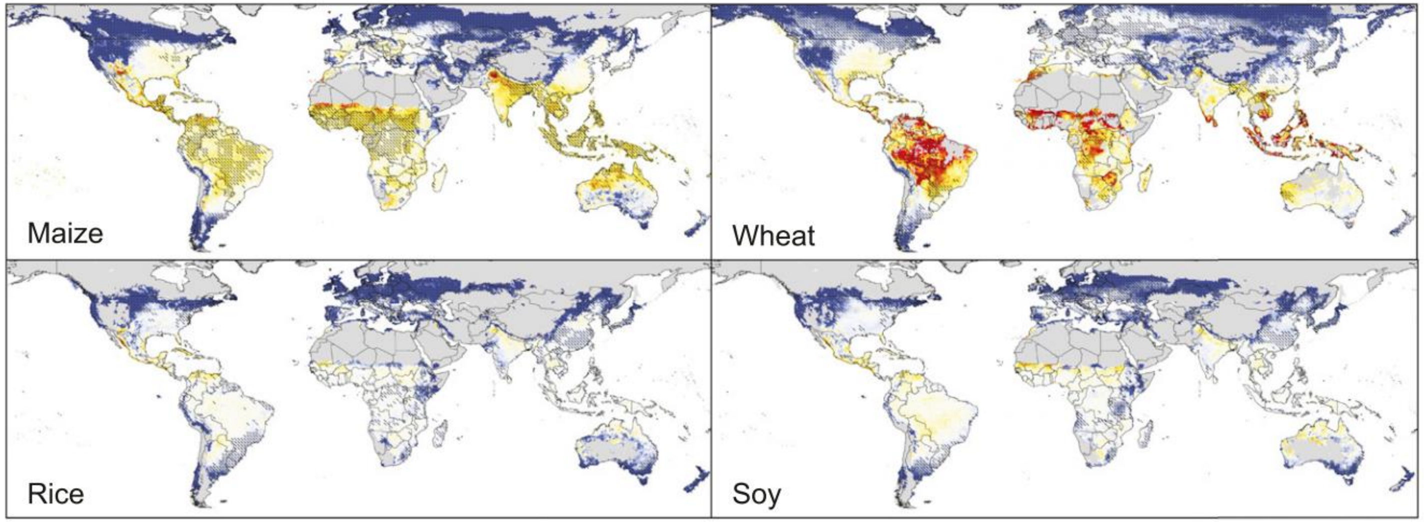
Crop growth simulation models

Crop models have been used to assess the climate change impact on crop growth

The studies are mainly focused on the yield of major food crops

- Wheat, rice, maize, soybean

Researches on perennial crop models are insufficient



Rosenzweig et al. (2014)

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., ... & Jones, J. W. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the national academy of sciences*, *111*(9), 3268-3273.

Climate suitability model

Compute suitability for a given climate condition

Can be applied for multiple crops more easily

Supplementary Table S3. Growing conditions for kiwis in Butte County, California, by month.

Month	Minimum temperature (°C)[1]	Maximum temperature (°C)[2]	Notes[3]
March	−3.85	19.16	Minimum precipitation is not incldued
April	−2.34	23.20	because limited moisture is typically
May	1.16	27.85	overcome with irrigation. Maximum
June	4.48	32.67	precipitation is not included because
July	7.85	36.87	excessive moisture is uncommon.
August	7.15	36.61	Minimum soil depth is 0.91 meters.
September	5.20	33.38	Acceptible soil texture classes are: sandy
October	0.82	27.26	loam and silt loam.[4]
November	−3.28	18.09	

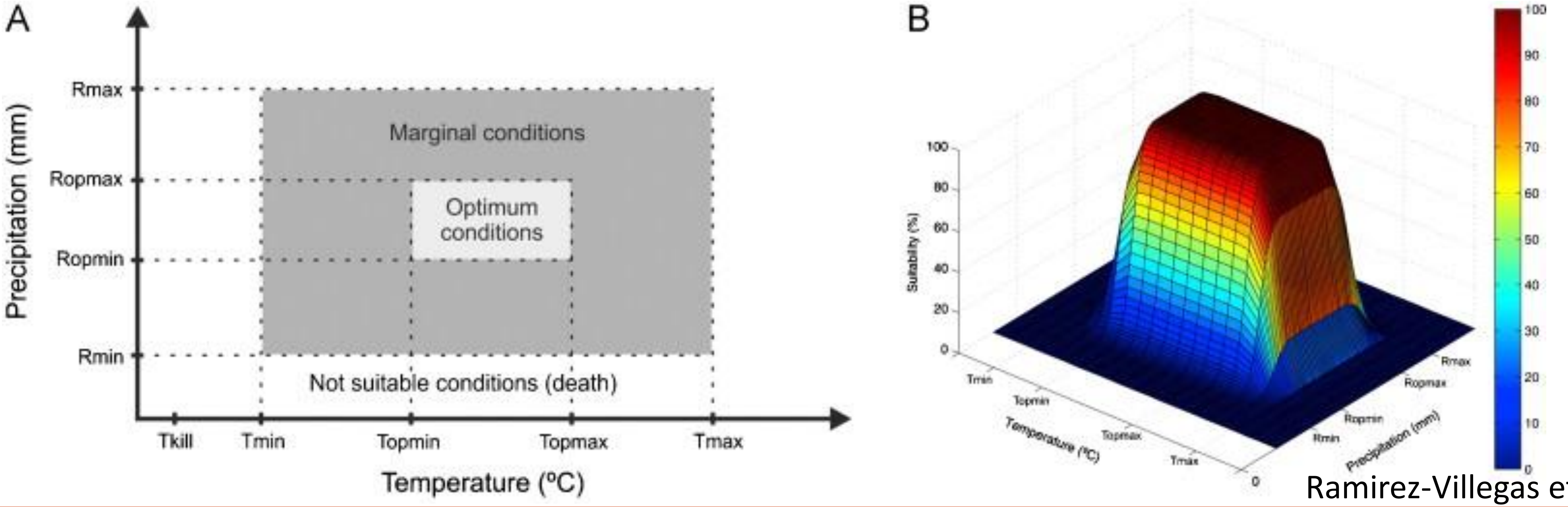
Conrad et al. (2017)

Conrad, Z., Peters, C. J., Chui, K., Jahns, L., & Griffin, T. S. (2017). Agricultural capacity to increase the production of select fruits and vegetables in the US: A geospatial modeling analysis. *International Journal of Environmental Research and Public Health*, *14*(10), 1106.

EcoCrop model

Developed based on FAO EcoCrop database

EcoCrop database provides default parameters for more than 2000 plant species



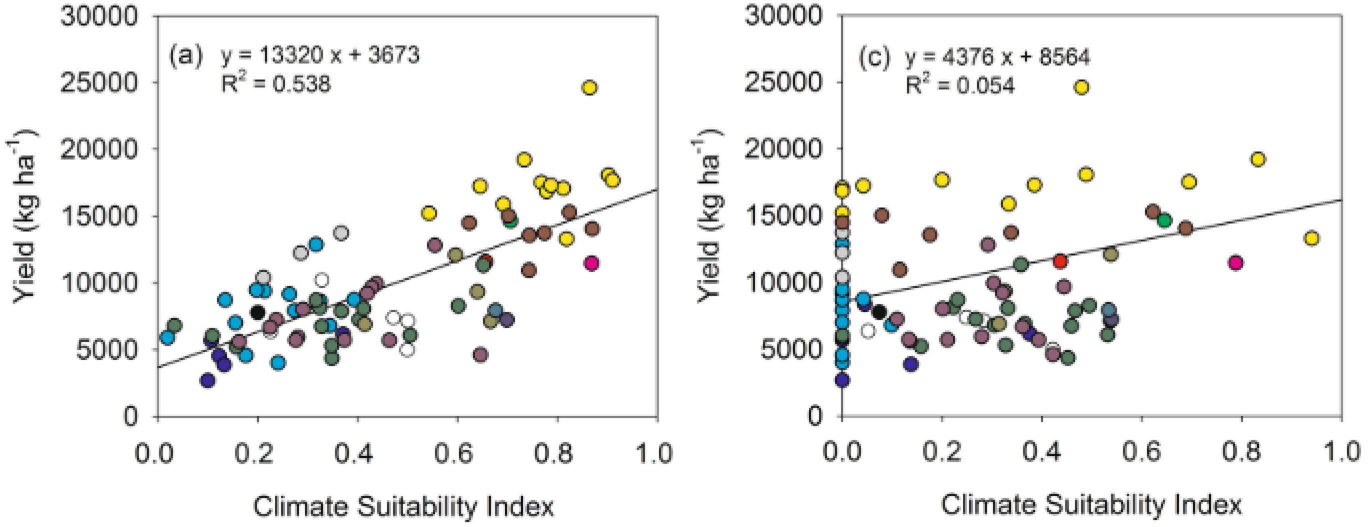
Ramirez-Villegas et al. (2013)

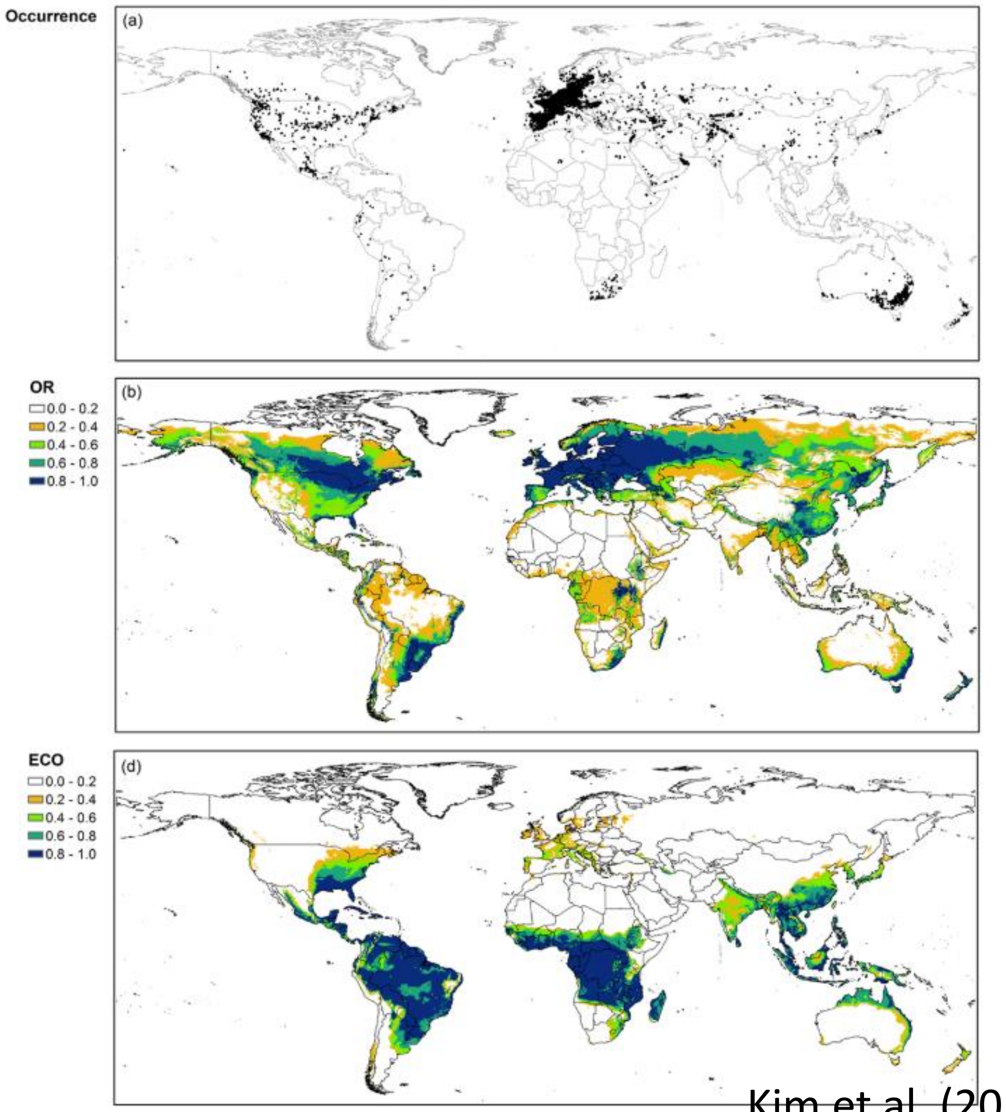
Ramirez-Villegas, J., Jarvis, A., & Läderach, P. (2013). Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. *Agricultural and Forest Meteorology*, *170*, 67-78.

Fuzzy logic model

Improved from EcoCrop model using fuzzy logic

Have been used in MOTIVE project





Kim et al. (2018)

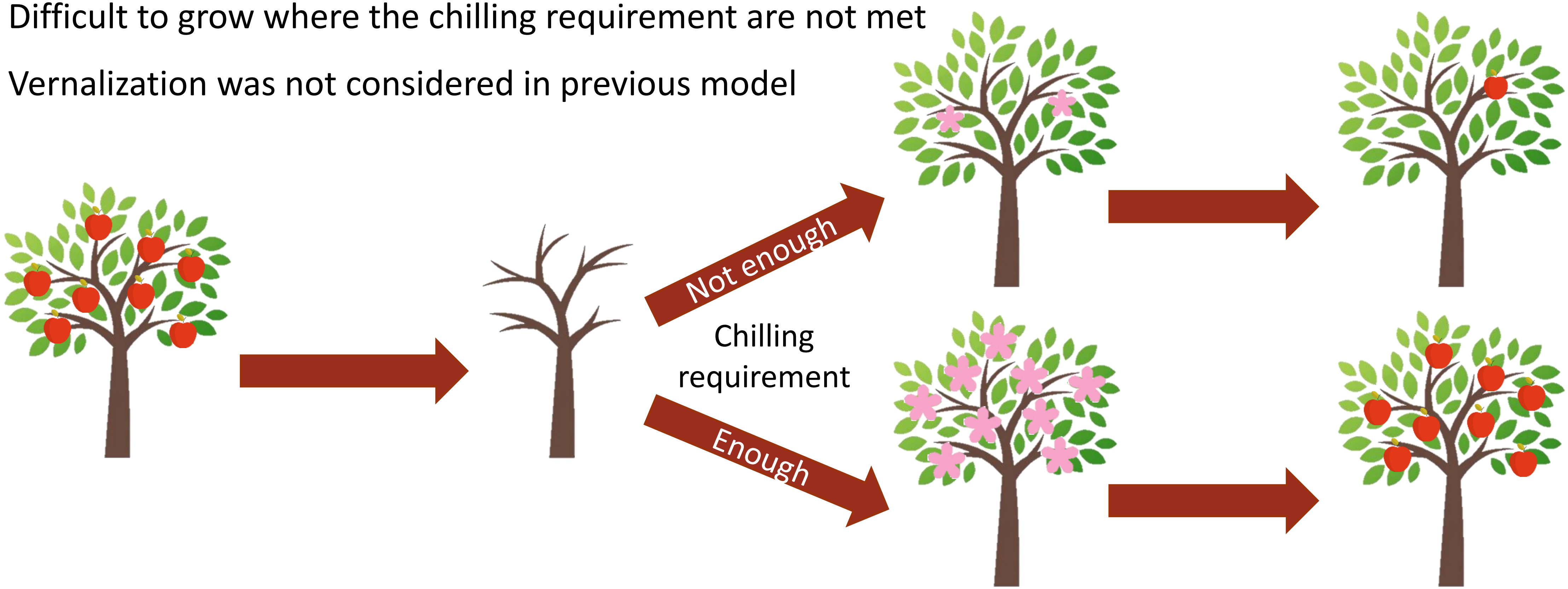
Kim, H., Hyun, S. W., Hoogenboom, G., Porter, C. H., & Kim, K. S. (2018). Fuzzy union to assess climate suitability of annual ryegrass (Lolium multiflorum), alfalfa (Medicago sativa) and sorghum (Sorghum bicolor). *Scientific reports*, *8*(1), 10220.

Vernalization

Many fruit crops require cold exposure to induce flowering and fruiting

Difficult to grow where the chilling requirement are not met

Vernalization was not considered in previous model



Objectives

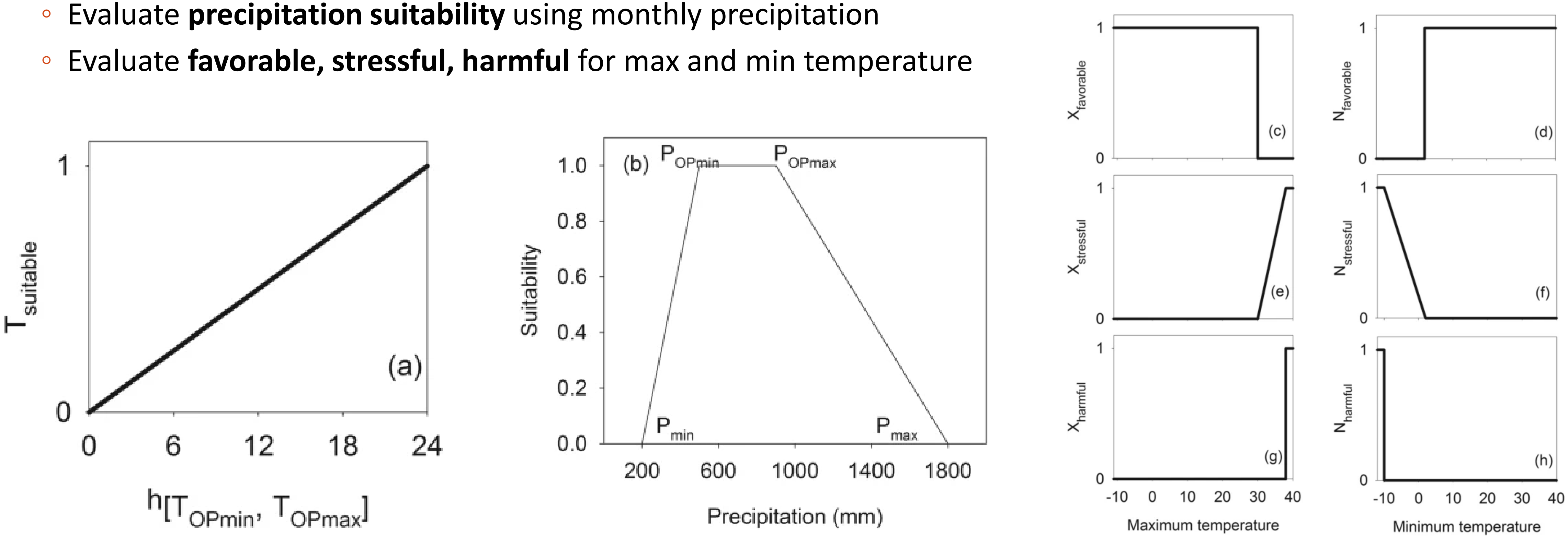
Develop a vernalization module and integrate into a climate suitability model

Calibrate parameters for the integrated suitability model

Fuzzy logic model

Compute climate suitability using monthly weather data (Kim et al., 2018).

- Evaluate **temperature suitability** based on duration of hours which the optimal conditions were met
- Evaluate **precipitation suitability** using monthly precipitation
- Evaluate **favorable, stressful, harmful** for max and min temperature

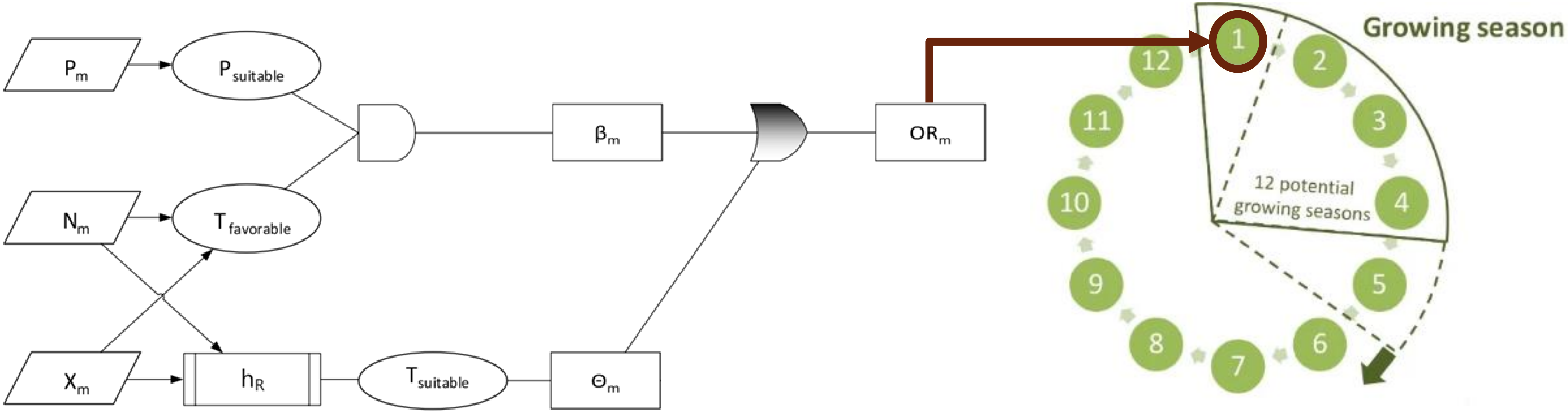


Kim, H., Hyun, S. W., Hoogenboom, G., Porter, C. H., & Kim, K. S. (2018). Fuzzy union to assess climate suitability of annual ryegrass (Lolium multiflorum), alfalfa (Medicago sativa) and sorghum (Sorghum bicolor). *Scientific reports*, *8*(1), 10220.

Fuzzy logic model

Determine **monthly suitability** by combining the conditions using fuzzy logic

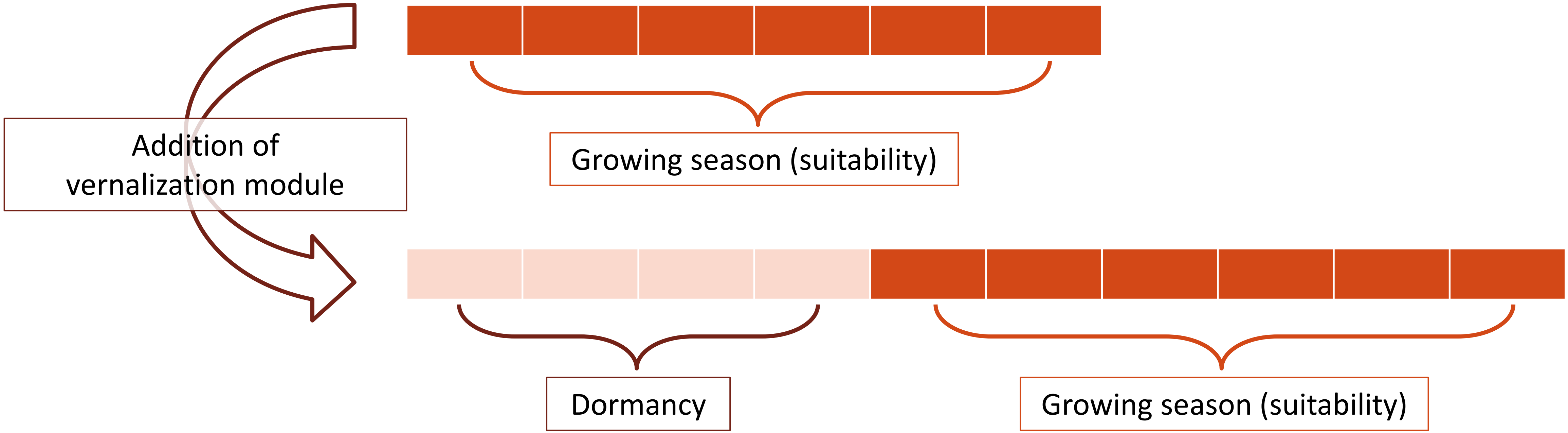
Determine **final suitability** considering growing periods and growing seasons



Vernalization module

Dormancy period due to cold exposure is calculated before growing season.

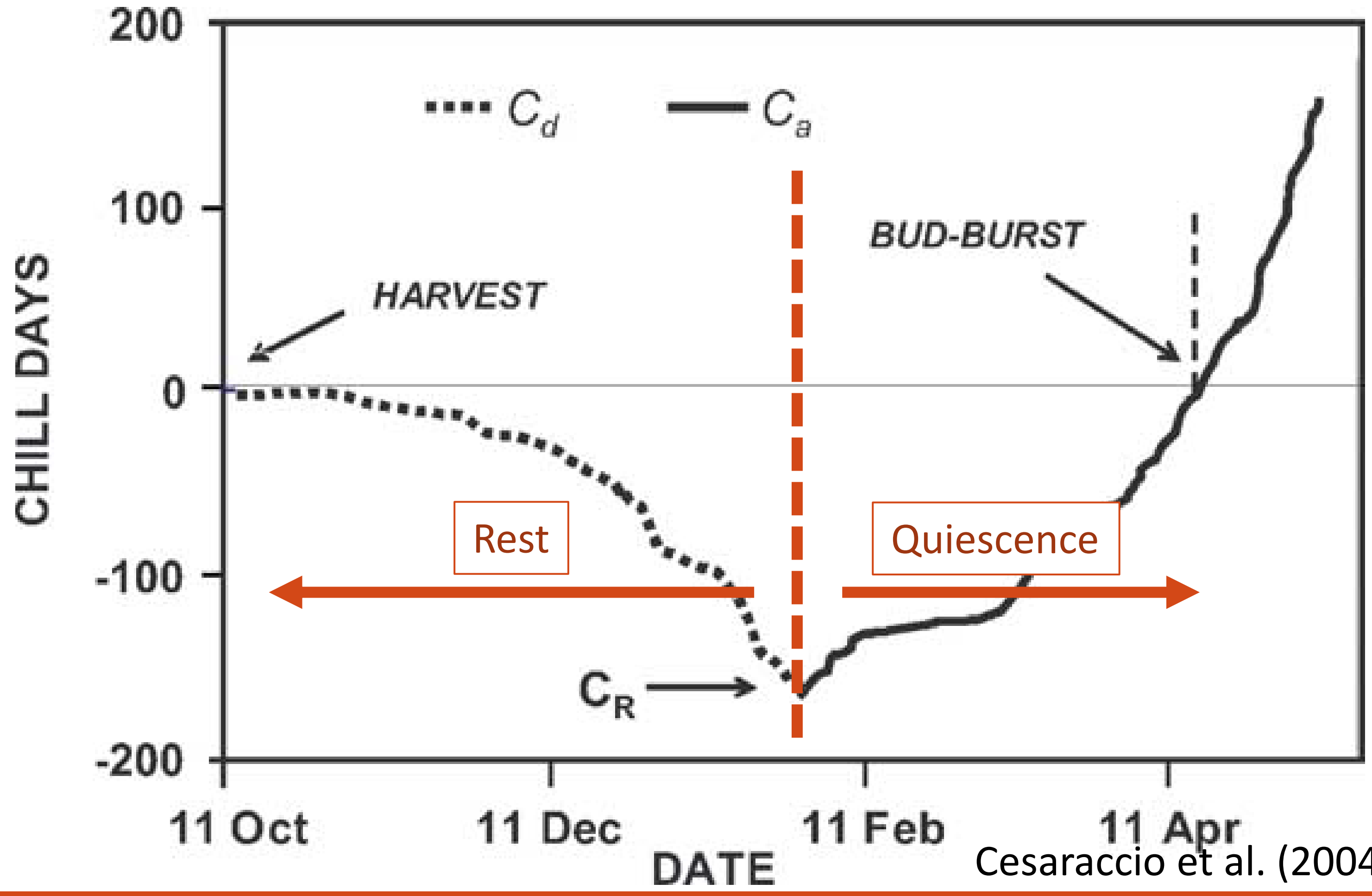
Not suitable if the crop does not go into dormancy or the duration of dormancy is too long.



Chill days model

1) Before meeting
   chilling requirement
   - Cumulate chill days

2) After meeting
   chilling requirement
   - Cumulate anti-chill days



Cesaraccio et al. (2004)

Cesaraccio, C., Spano, D., Snyder, R. L., & Duce, P. (2004). Chilling and forcing model to predict bud-burst of crop and forest species. *Agricultural and Forest Meteorology*, *126*(1-2), 1-13.

Chill days model

Chill days (C_d) and anti-chill days (C_a) are calculated differently depending on temperature condition

Require **T_C (threshold)** and **C_R (chilling requirement)** for a crop

Number	Temperature cases	Chill days	Anti-chill days
1	$0 \leq T_C \leq T_n \leq T_x$	$C_d = 0$	$C_a = T_M - T_C$
2	$0 \leq T_n \leq T_C < T_x$	$C_d = -\left[(T_M - T_n) - \left(\frac{(T_x - T_C)}{2}\right)\right]$	$C_a = \frac{T_x - T_C}{2}$
3	$0 \leq T_n \leq T_x \leq T_C$	$C_d = -(T_M - T_n)$	$C_a = 0$
4	$T_n < 0 < T_x \leq T_C$	$C_d = -\left(\frac{T_x}{T_x - T_n}\right)\left(\frac{T_x}{2}\right)$	$C_a = 0$
5	$T_n < 0 < T_C < T_x$	$C_d = -\left[\left(\frac{T_x}{T_x - T_n}\right)\left(\frac{T_x}{2}\right) - \left(\frac{T_x - T_C}{2}\right)\right]$	$C_a = \frac{T_x - T_C}{2}$

Parameters

model	Parameter	Description	Parameter	Description	Parameter	Description
Chill day model	Tc	Threshold for chill days	Cr	Chilling requirement		
Fuzzy logic model	Gmin	Minimum growing season	Tmin	Minimum temperature	Rmin	Minimum rainfall
	Gmax	Maximum growing season	TOPmin	Optimum minimum temperature	ROPmin	Optimum minimum rainfall
	TKill	Killing temperature	TOPmax	Optimum maximum temperature	ROPmax	Optimum maximum rainfall
			Tmax	Maximum temperature	Rmax	Maximum rainfall

Calibration

Generalized Likelihood Uncertainty Estimation (GLUE) method

- Popular method to calibrate model parameters

Calibration process follows:

- Generate random parameter sets
- Run model to generate suitability map using each parameter sets
- Calculate likelihood value for each map by comparing with occurrence data
- Calculate probability for each parameter sets
- Determine final parameter set using probability values

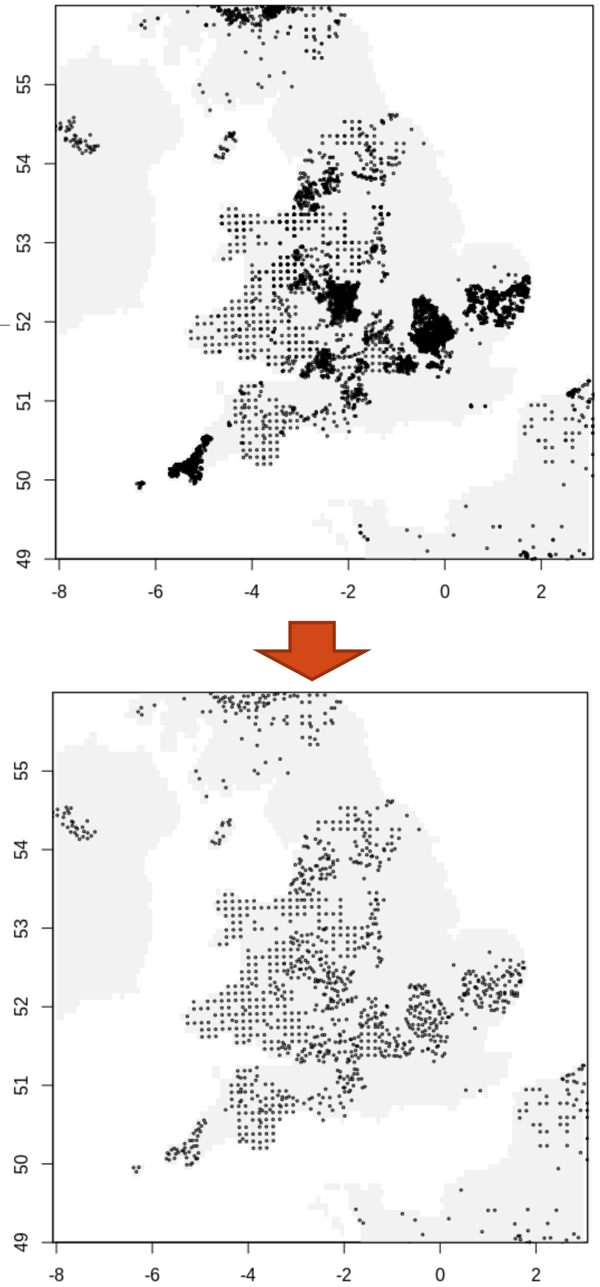
Calibration data

Gridded weather data

- WorldClim data
- Historical condition for 1971 ~ 2000
- Resolution : 10 km (5 arc-minutes)

Occurrence data

- Apple (*Malus domestica* Borkh.)
- Global Biodiversity Information Facility (GBIF) occurrence data
- Data for 1971 ~ 2000 were used
- Data were filtered to 10 x 10 km due to overlapped data



Validation

Suitability values over 0 were used to compare with statistical data

- Not suitable where the suitability values are 0

Mean suitability values were compared with yield

- Apple yield (kg/ha) from FAOSTAT
- Data for 1971 ~ 2000 was used

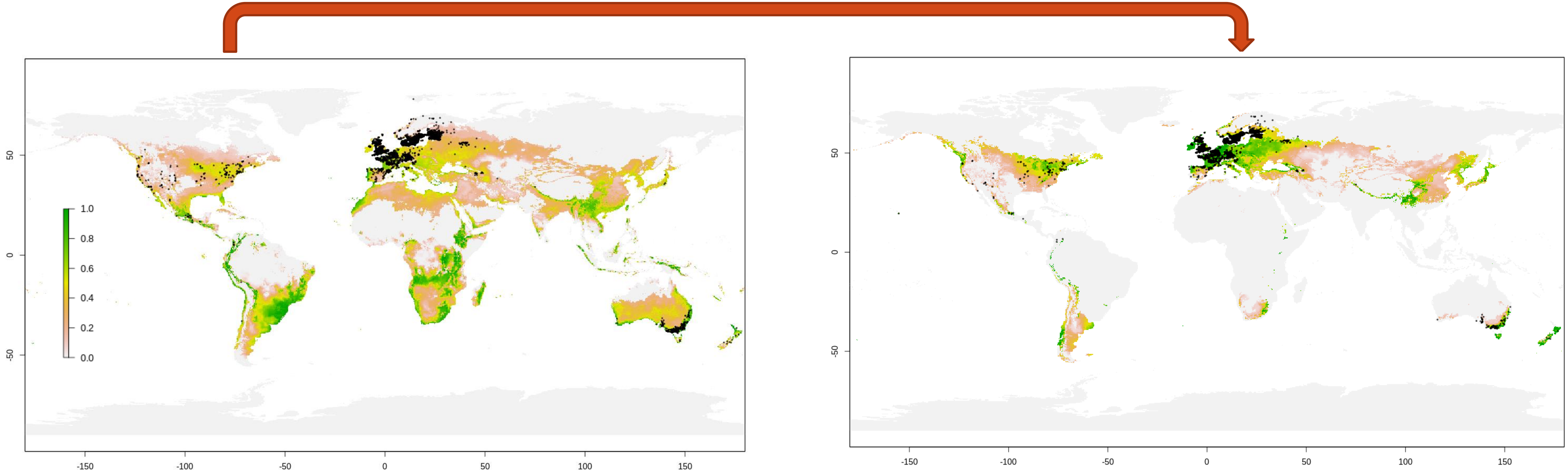
Suitable areas were compared with harvested areas

- Apple harvested area (ha) from FAOSTAT
- Data for 1971 ~ 2000 was used

Results

Suitability values increased near the occurrence sites

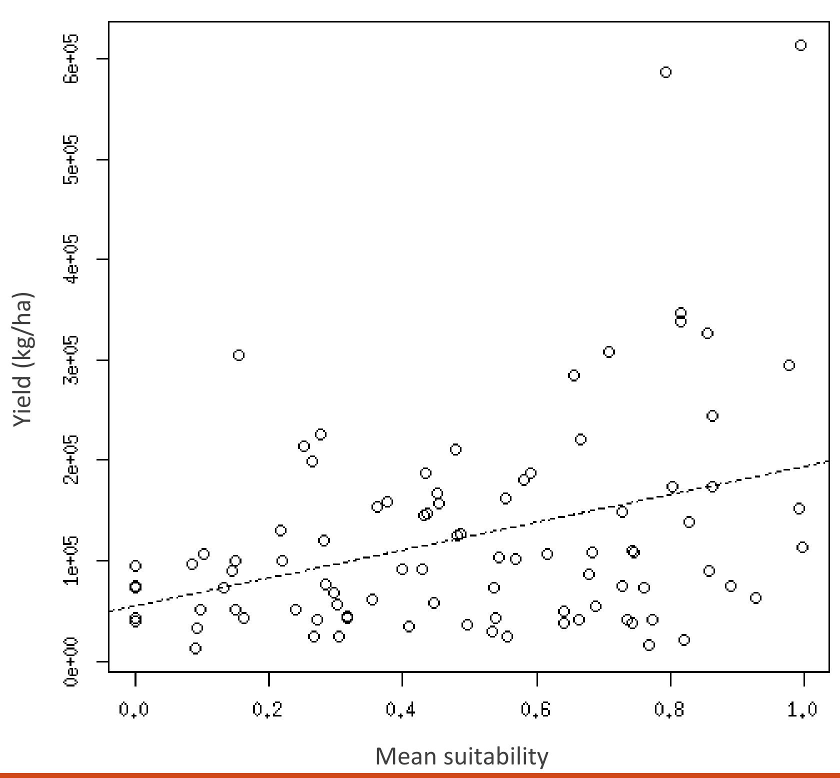
Suitable areas were reduced, especially in regions with warm climate conditions

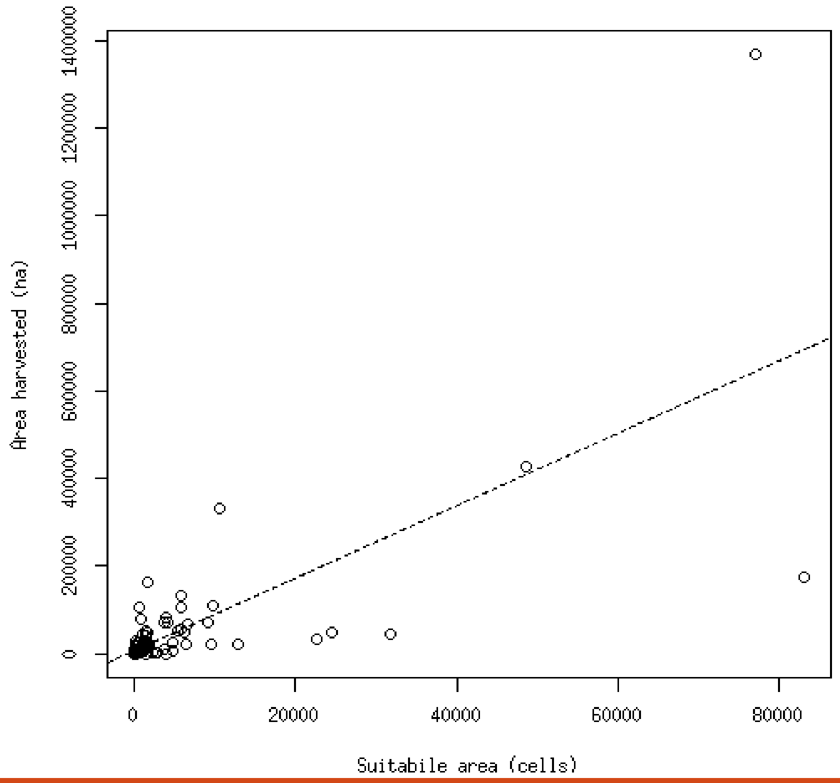


Validation

Tendency for high yield in countries with high suitability

Tendency for large harvested area in countries with a large suitable area





Discussion

Spatial bias of GBIF data

- Concentrated in northern hemisphere, specifically in Europe
- Due to uneven effort of sampling, data storage and mobilization

Resolution of weather data

- Spatial resolution - 10km
- Temporal resolution - monthly

Cultivation area would be affected by non-climatic factors

Discussion

Evaluation of climate suitability in high spatial resolution could be considered

- Use spatial resolution at 1km

Evaluation of climate suitability for other fruit trees could be considered

- Fruit trees which requires vernalization process
- Pear, peach

Summary

Estimation of climatic suitable area would be useful to decide cultivation area of a crop

Fuzzy logic model was integrated with vernalization module

Integrated model resulted in more accurate suitable area for apple

Evaluation for other fruits and different spatial resolution should be performed

Thank you!

Let’s continue the conversation!

Post questions and comments in the IAIA23 app.

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