PyAEZ: Applying Yield Reduction Factors

PyAEZ MODULE III, IV and V

Asian Institute of Technology

Content

1. Introduction to Crop Simulations

What's Next

- Now we have simulated and found maximum yield that we can obtain under climate conditions in the study area.

- But so far, we have ignored other factors such as soil, slope, other climate related phenomenon like pest and deceases.

- These factors are hard to model deterministically. To get around this issue, we will apply empirical reduction factors to take into account these phenomenons.

- AEZ provide a guideline to do that. But these are straightforward formulas compared to crop simulation module. You can perform them in any GIS software as well. Since we use Python here, let's go ahead and apply them with PyAEZ.

Applying Yield Reduction Factors

- We will perform all reduction factors based on following areas

1. Module III: Applying Climate Constraints

2. Module IV: Applying Soil Constraints

3. Module V: Applying Terrain Constraints

Applying Yield Reduction Factors

- All reduction factors need to be added in following 2 parameter files located in "code" folder

  - **ALL_REDUCTION_FACTORS_IRR.py** – reduction factors for irrigated conditions
  - **ALL_REDUCTION_FACTORS_RAIN.py** – reduction factors for rain-fed conditions

- All reduction factors are given as Python lists. All details are in PyAEZ documentation.

Screenshot of Parameter File

```
'''-----------------------------------------------------------'''
'''Reduction Factors for Climatic Constraints'''
'''-----------------------------------------------------------'''

#defining yield reduction factors based of LGP Equivalent class
lgp_eq_class = [[0,29],[30,59],[60,89],[90,119],[120,149],[150,179],[180,
209],[210,239],[240,269],[270,299],[300,329],[330,366]]
lgp_eq_red_fr = [[25,25,25,25,25,25,25,50,50,50,75,75],
                 [100,100,100,100,100,100,100,100,100,100,100,100],
                 [50,50,50,50,50,75,75,100,100,100,100,75],
                 [100,100,100,100,100,100,100,100,100,100,100,75]]

'''-----------------------------------------------------------'''
'''Reduction Factors for Soil Constraints'''
'''-----------------------------------------------------------'''

# value - values of soil characteristics (mush be ascending order)
# factor - yield reduction factors corresponding to each value
```

Module III: Applying Climate Constraints

Applying Climate Constraints

- Even though, we have used climate data extensively in Module II with mathematical models.

- Some aspect of effects of climate such as pest, diseases, workability, etc. is hard to capture with deterministic models.

- So the purpose of this module is to provide guideline to apply reduction factors for those climate effects that hard to model mathematically.

Applying Climate Constraints

- So climate constraints will be applying under following 4 themes.

  a) Yield adjustment due to year-to-year variability of soil moisture supply; this factor is applied to adjust yields calculated for average climatic conditions

  b) Yield losses due to the effect of **pests, diseases and weed constraints** on crop growth

  c) Yield losses due to **water stress, pest and diseases** constraints on yield components and yield formation of produce (e.g., affecting quality of produce)

  d) Yield losses due to soil **workability constraints** (e.g., excessive wetness causing difficulties for harvesting and handling of produce)

Equivalent LGP

- Moisture conditions effecting above sections are known to be well explained with Equivalent Length of Growing Period (LGP)

- This is calculated in Module I. Equivalent LGP (LGPeq) has been calculated based on regression equations between the Reference LGP and the Humidity Index P/Eto, and equation for that is given below,

$$LGPeq = \begin{cases} 14.0 + 293.66 \times \left(\frac{P}{ETo}\right) - 61.25 \times \left(\frac{P}{ETo}\right)^2 & ; \quad when \left(\frac{P}{ETo}\right) \leq 2.4; \\ 366 & ; \quad when \left(\frac{P}{ETo}\right) > 2.4; \end{cases}$$

Parameter File

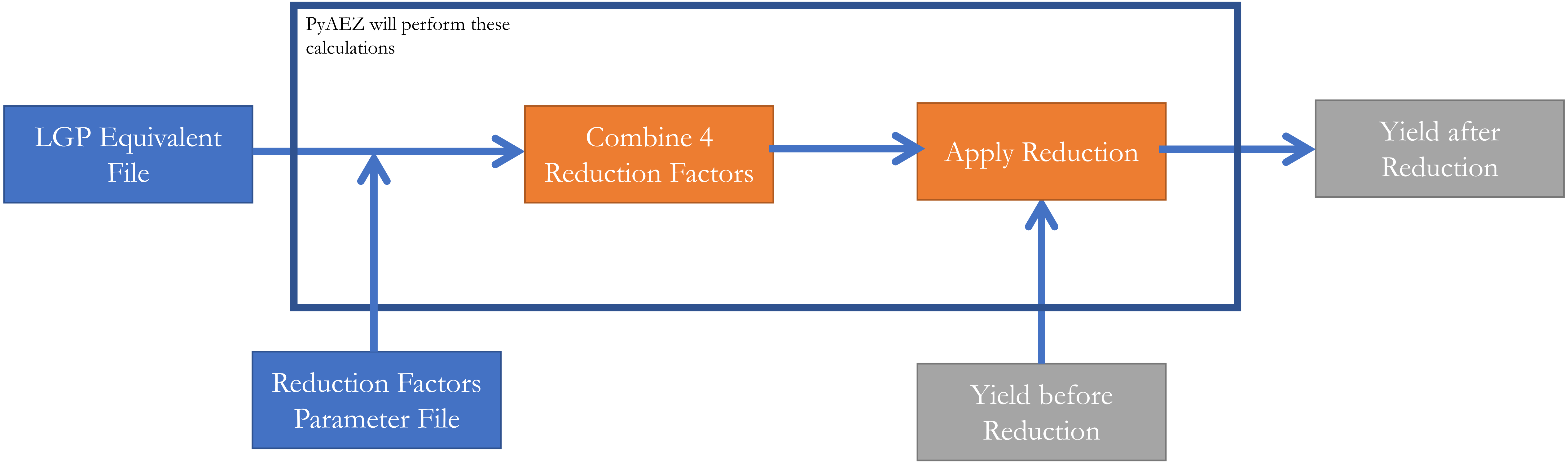
- First, we have to add reduction factors and related parameters (for the crop-input level combination that we are running) as lists in parameter files (rain-fed and irrigated parameter files).

```
'''-----------------------------------------'''
'''Reduction Factors for Climatic Constraints'''
'''-----------------------------------------'''

#defining yield reduction factors based of LGP Equivalent class
lgp_eq_class = [[0,29], [30,59], [60,89], [90,119], [120,149], [150,179], [180,209], [210,239], [240,269], [270,299], [300,329], [330,366]]

lgp_eq_red_fr = [[25,25,25,25,25,25,25,50,50,50,75,75],
[100,100,100,100,100,100,100,100,100,100,100,100],
[50,50,50,50,50,75,75,100,100,100,100,75],
[100,100,100,100,100,100,100,100,100,100,100,75]]
```

How it works


PyAEZ will perform these calculations
LGP Equivalent File
Combine 4 Reduction Factors
Apply Reduction
Yield after Reduction
Reduction Factors Parameter File
Yield before Reduction

Example

- In particular location LGP_eq is 95, reduction factor will be = Minimum (100, 0, 50, 0) = 50 %
- So yield will be reduced by 50% in this module.

LGP_eq class	0	1-29	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	270-299	300-329	330-364	365	366
a	100	100	100	100	100	100	100	50	50	50	25	25	25	0	0
b	0	0	0	0	0	0	0	0	0	0	0	0	0	0	25
c	50	50	50	50	50	50	25	25	0	0	0	25	25	25	25
d	0	0	0	0	0	0	0	0	0	0	0	0	25	25	50

Module IV: Applying Soil Constraints

Applying Soil Constraints

- After Applying Climate Reduction Factors, now, we will apply Soil related reduction factors

- You can use either global soil dataset like Harmonized World Soil Database (HWSD) or your own soil dataset.

Soil Data Set

- Soil map are prepared as raster data

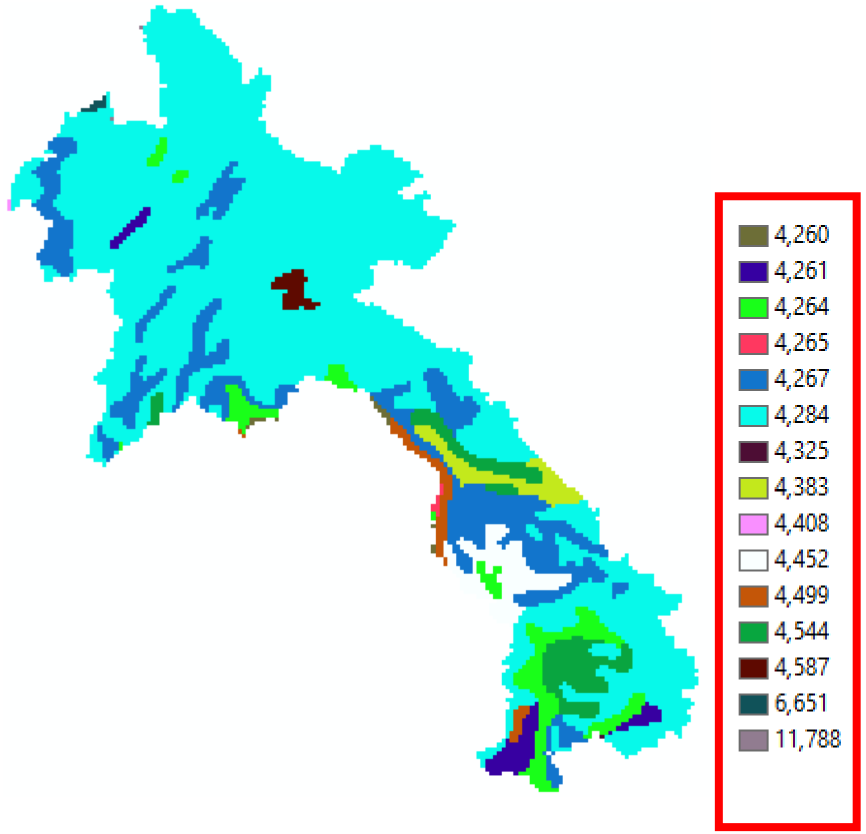
- Soil characteristics (attribute) can be prepared as CSV files. There are 2 separate CSV files for both Top soil and sub soil as below,

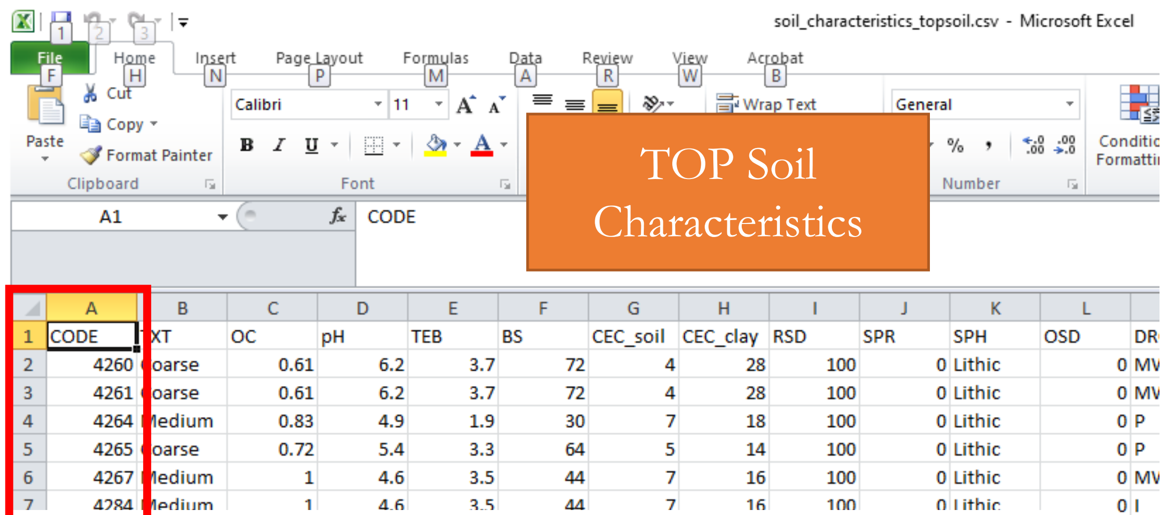
  - **soil_characteristics_topsoil.csv**: Soil characteristics of top soil (located in ./*sample data*/*input* folder).

  - **soil_characteristics_subsoil.csv**: Soil characteristics of sub soil (located in ./*sample data*/*input* folder).

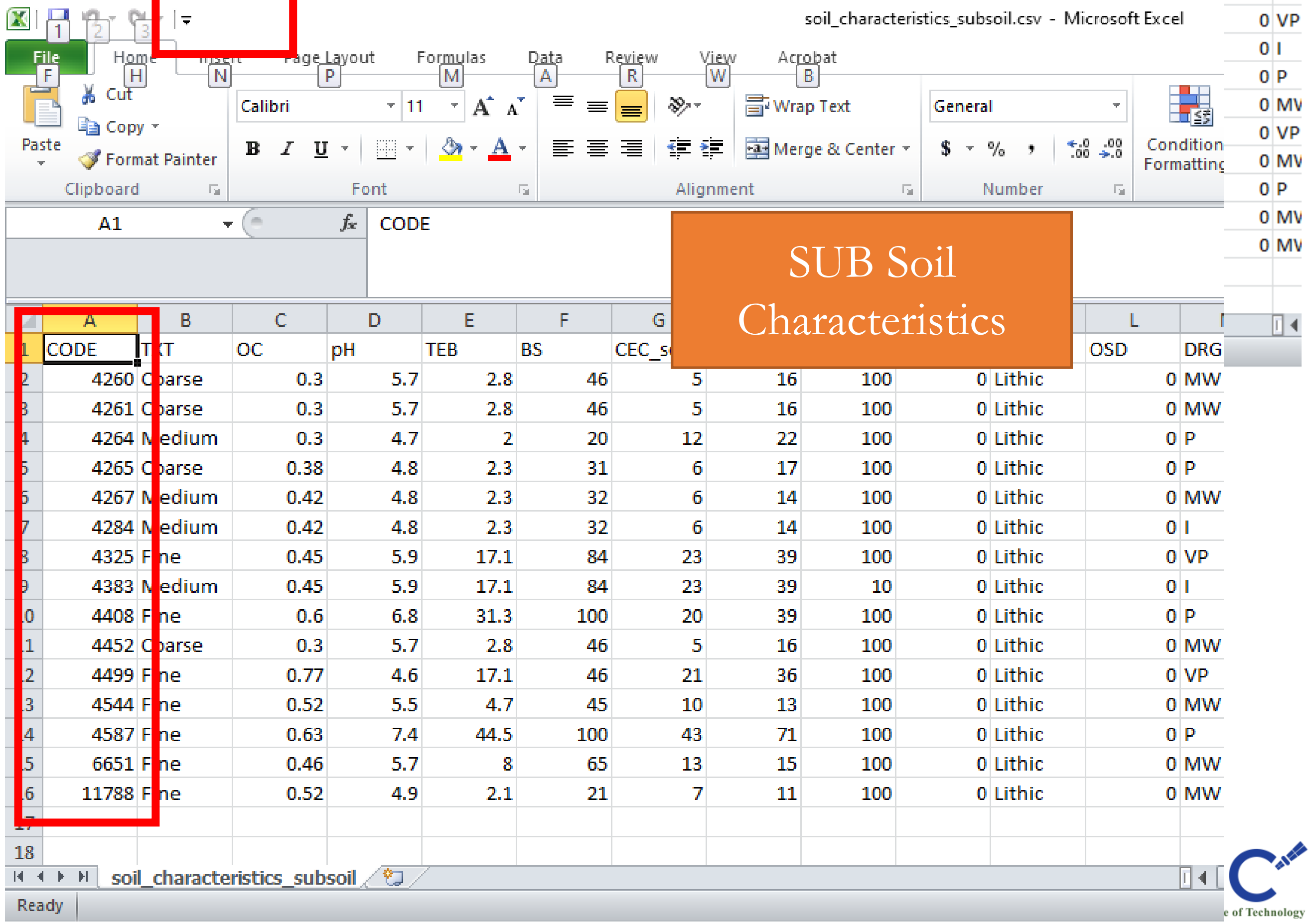
Example Soil Data Set

Soil map and soil characteristics are linked through soil unit code





CODE	TXT	OC	pH	TEB	BS	CEC_soil	CEC_clay	RSD	SPR	SPH	OSD	DR
4260	Coarse	0.61	6.2	3.7	72	4	28	100	0	Lithic	0	MV
4261	Coarse	0.61	6.2	3.7	72	4	28	100	0	Lithic	0	MV
4264	Medium	0.83	4.9	1.9	30	7	18	100	0	Lithic	0	P
4265	Coarse	0.72	5.4	3.3	64	5	14	100	0	Lithic	0	P
4267	Medium	1	4.6	3.5	44	7	16	100	0	Lithic	0	MV
4284	Medium	1	4.6	3.5	44	7	16	100	0	Lithic	0	I



CODE	TXT	OC	pH	TEB	BS	CEC_s					OSD	DRG
4260	Coarse	0.3	5.7	2.8	46	5	16	100	0	Lithic	0	MW
4261	Coarse	0.3	5.7	2.8	46	5	16	100	0	Lithic	0	MW
4264	Medium	0.3	4.7	2	20	12	22	100	0	Lithic	0	P
4265	Coarse	0.38	4.8	2.3	31	6	17	100	0	Lithic	0	P
4267	Medium	0.42	4.8	2.3	32	6	14	100	0	Lithic	0	MW
4284	Medium	0.42	4.8	2.3	32	6	14	100	0	Lithic	0	I
4325	Fine	0.45	5.9	17.1	84	23	39	100	0	Lithic	0	VP
4383	Medium	0.45	5.9	17.1	84	23	39	10	0	Lithic	0	I
4408	Fine	0.6	6.8	31.3	100	20	39	100	0	Lithic	0	P
4452	Coarse	0.3	5.7	2.8	46	5	16	100	0	Lithic	0	MW
4499	Fine	0.77	4.6	17.1	46	21	36	100	0	Lithic	0	VP
4544	Fine	0.52	5.5	4.7	45	10	13	100	0	Lithic	0	MW
4587	Fine	0.63	7.4	44.5	100	43	71	100	0	Lithic	0	P
6651	Fine	0.46	5.7	8	65	13	15	100	0	Lithic	0	MW
11788	Fine	0.52	4.9	2.1	21	7	11	100	0	Lithic	0	MW

Soil Characteristic List

TXT: soil texture (Strings)	DRG: drainage class (VP: very poor, P: Poor, I: Imperfectly, MW: Moderately well, W: Well, SE: Somewhat Excessive, E: Excessive)
OC: soil organic carbon (numerical values)	ESP: exchangeable sodium percentage
pH: soil pH (numerical values)	EC: electric conductivity (dS/m)
TEB: total exchangeable bases (numerical values)	SPH: soil phase rating (either 0 or 1)
BS: base saturation (numerical values)	SPR: soil property rating (either 0 or 1)
CECsoil: cation exchange capacity of soil (numerical values)	OSD: other soil depth/volume related characteristics rating
CECclay: cation exchange capacity of clay (numerical values)	CCB: calcium carbonate content as Percentage
RSD: effective soil depth (numerical values)	GYP: gypsum content as Percentage
GRC: soil coarse material (Gravel) as Percentage	VSP: vertical properties (either 0 or 1)

Parameter File

- First, we have to add reduction factors crop-input level combination that we are running) as lists in parameter files (rain-fed and irrigated parameter files).

```

'''-----------------------------------------'''
'''Reduction Factors for Soil Constraints'''
'''-----------------------------------------'''

# value - values of soil characteristics (must be ascending
    order)
# factor - yield reduction factors corresponding to each
   value

# soil texture
TXT_value = ['Fine', 'Medium', 'Coarse']
TXT_factor = [90, 70, 30]

# soil organic carbon
OC_value = [0, 0.8, 1.5, 2]
OC_factor = [50, 70, 90, 100]

# soil pH
pH_value = [3.6, 4.1, 4.5, 5, 5.5, 6]
pH_factor = [10, 30, 50, 70, 90, 100]

# total exchangeable bases
TEB_value = [0, 1.6, 2.8, 4, 6.5]
TEB_factor = [30, 50, 70, 90, 100]

# base saturation
BS_value = [0, 35, 50, 80]
```

Calculating Soil Qualities

- Rather than applying reduction factors directly based on soil characteristic, AEZ methodology recommend to apply reduction factors through following 7 soil qualities

Soil Qualities		Soil quality related soil profile attributes, soil drainage conditions and soil phase characteristics
SQ1	Nutrient availability.	Soil texture, soil organic carbon, soil pH, total exchangeable bases.
SQ2	Nutrient retention capacity.	Soil texture, base saturation, cation exchange capacity of soil and of clay fraction.
SQ3	Rooting conditions.	Soil textures, coarse fragments, vertic soil properties and soil phases affecting root penetration and soil depth and soil volume.
SQ4	Oxygen availability to roots.	Soil drainage and soil phases affecting soil drainage
SQ5	Excess salts.	Soil salinity, soil sodicity and soil phases influencing soil salinity and sodicity conditions.
SQ6	Toxicity.	Calcium carbonate and gypsum.
SQ7	Workability (constraining field management).	Soil texture, effective soil depth/volume, and soil phases constraining soil management (soil depth, rock outcrop, stoniness, gravel/concretions and hardpans).

Calculating Soil Qualities

- Typically Soil qualities are calculated with following equation. These equations are different for each soil quality, but generally in this form. For more details, please have a look on GAEZ documentation.

Let $(x_1,....,x_m)$ be a vector of soil attributes relevant for a particular soil quality SQ and $(\tau(x_1),..., \tau(x_m))$ the vector of respective soil attribute ratings, $0 \le \tau(x_j) \le 100$.

Further, let j_o denote the soil attribute with the lowest rating such that:

$$\tau(x_{jo}) \le \tau(x_j),\ j = 1,...,m.$$

Then we define soil quality SQ as a weighted sum of soil attribute ratings, as follows:

$$SQ = f_{SQ}(x_1, \dots, x_m) = \frac{\tau(x_{j_0}) + \frac{1}{m-1}\sum_{j \neq j_0} \tau(x_j)}{2}$$

Example

- If in a particular place
  - TXT = Fine → 90%
  - OC = 0.8 → 70%
  - pH = 4.1 → 30%
  - TEB = 1.6 → 50%

SQ1 will be = (30 + (90+70+50)/3)/2 = 50 %

```
'''----------------------------------------'''
'''Reduction Factors for Soil Constraints'''
'''----------------------------------------'''

# value - values of soil characteristics (must be ascending
    order)
# factor - yield reduction factors corresponding to each
   value

# soil texture
TXT_value = ['Fine', 'Medium', 'Coarse']
TXT_factor = [90, 70, 30]

# soil organic carbon
OC_value = [0, 0.8, 1.5, 2]
OC_factor = [50, 70, 90, 100]

# soil pH
pH_value = [3.6, 4.1, 4.5, 5, 5.5, 6]
pH_factor = [10, 30, 50, 70, 90, 100]

# total exchangeable bases
TEB_value = [0, 1.6, 2.8, 4, 6.5]
TEB_factor = [30, 50, 70, 90, 100]

# base saturation
BS_value = [0, 35, 50, 80]
```

Calculating Soil Qualities

- Soil Qualities are calculated for top and sub soil separately. And they are combined by taking average as below

$$Final\ SQ = \frac{SQ\ of\ Top\ Soil + SQof\ Sub\ Soil}{2}$$

Calculating Soil Qualities

- And finally all 7 soil qualities are combined to get final reduction factor based in input level as below. This final reduction factor is names as Soil Rating.

Low input farming:

*SRlow = SQ1*SQ3*fSQ(SQ4, SQ5, SQ6, SQ7)*

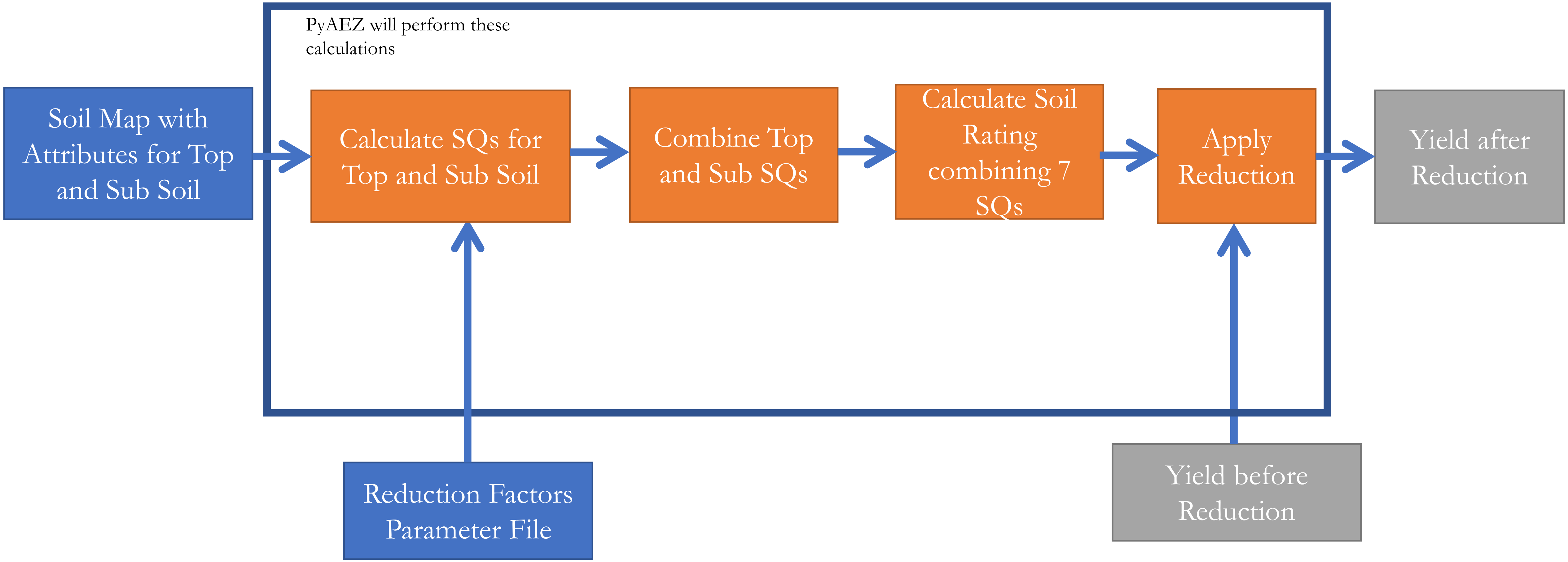
Intermediate input farming:

*SRint. = 0.5 * (SQ1+SQ2)*SQ3* fSQ(SQ4, SQ5, SQ6, SQ7)*

High input farming:

*SRhigh = SQ2*SQ3* fSQ(SQ4, SQ5, SQ6, SQ7)*

How it works


PyAEZ will perform these calculations
Soil Map with Attributes for Top and Sub Soil
Calculate SQs for Top and Sub Soil
Combine Top and Sub SQs
Calculate Soil Rating combining 7 SQs
Apply Reduction
Yield after Reduction
Reduction Factors Parameter File
Yield before Reduction

Module V: Applying Terrain Constraints

Module V: Applying Terrain Constraints

- After applying soil constraints in the Module IV, terrain constraints can be applied in this module.

- Slope and soil erosion related constraints with Fournier index (FI) which is based on monthly precipitation are applied in this section.

Module V: Applying Terrain Constraints

- The intensity of rainfall and the slope angles are the main driving factors of soil erosion.

- To account for slope angles, following six classes have been introduced (you can use your own classifications as well)
  - 0-0.5% very flat
  - 0.5-2% flat
  - 2-5% gently sloping
  - 5-8 % undulating
  - 8-16% rolling
  - 16-30% hilly
  - 30-45% steep
  - > 45% very steep.

Module V: Applying Terrain Constraints

- Fournier index (Fm) captures effect of rainfall. Fm equation is shown below,

$$Fm = \frac{12\sum_{i=1}^{12} P_i^{\,2}}{\sum_{i=1}^{12} P_i}$$

where, P_i = precipitation of month i

- And reduction factors are defined for each combinations of Fm class and slope class.

Parameter File

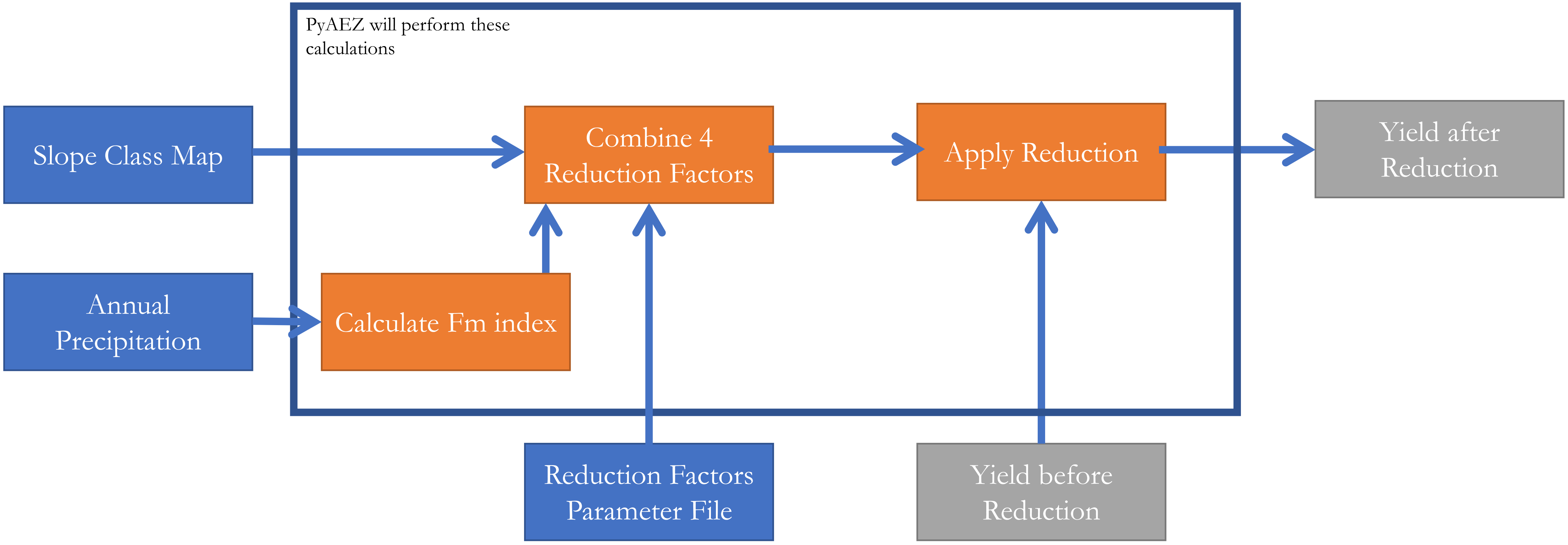
- First, we have to add reduction factors and related parameters (for the crop-input level combination that we are running) as lists in parameter files (rain-fed and irrigated parameter files).

```
'''---------------------------------------'''
'''Reduction Factors for Terrain Constraints'''
'''---------------------------------------'''

Slope_class = [[0,0.5], [0.5,2], [2,5], [5,8], [8,16],
    [16,30], [30,45], [45,100]] # classes of slopes (
    Percentage Slope)
FI_class = [[0,1300], [1300,1800], [1800,2200],
    [2200,2500], [2500,2700], [1700,100000]] # classes of
    Fournier index

# sample data are for irrigated-intermediate input-wetland
    rice
# rows corresponding to FI classed and columns
    corresponding to slope classes
Terrain_factor = [[100, 100,  75, 50, 25, 0,  0,  0],
[100, 100,  100,  100,  100,  75, 0,  0],
[100, 100,  100,  100,  75, 25, 0,  0],
[100, 100,  100,  100,  50, 0,  0,  0],
[100, 100,  100,  100,  25, 0,  0,  0],
[100, 100,  100,  100,  25, 0,  0,  0]]
```

How it works


PyAEZ will perform these calculations
Slope Class Map
Combine 4 Reduction Factors
Apply Reduction
Yield after Reduction
Annual Precipitation
Calculate Fm index
Reduction Factors Parameter File
Yield before Reduction

Example

- if a place has slope of 3% and FI index is 1500. What will be the reduction factor ?

100% - so yield will not be reduced in this place

```
'''-----------------------------------------'''
'''Reduction Factors for Terrain Constraints'''
'''-----------------------------------------'''

Slope_class = [[0,0.5], [0.5,2], [2,5], [5,8], [8,16],
    [16,30], [30,45], [45,100]] # classes of slopes (
    Percentage Slope)
FI_class = [[0,1300], [1300,1800], [1800,2200],
    [2200,2500], [2500,2700], [1700,100000]] # classes of
    Fournier index

# sample data are for irrigated-intermediate input-wetland
    rice
# rows corresponding to FI classed and columns
    corresponding to slope classes
Terrain_factor = [[100, 100,  75, 50, 25, 0,  0,  0],
[100, 100,  100,  100,  100,  75, 0,  0],
[100, 100,  100,  100,  75, 25, 0,  0],
[100, 100,  100,  100,  50, 0,  0,  0],
[100, 100,  100,  100,  25, 0,  0,  0],
[100, 100,  100,  100,  25, 0,  0,  0]]
```

Exercise

- if a place has slope of 6% and FI index is 2000. What will be the reduction factor ?

Summary

- We apply reduction factors for
  - Module III: Applying Climate Constraints
    - Depend on LGP equivalent
    - And 4 sets of consideration
  - Module IV: Applying Soil Constraints
    - Apply through 7 soil qualities
    - We have to prepare soil layers as raster file and attributes in CSV format.
  - Module V: Applying Terrain Constraints
    - Depend on slope class and FI index class (based on annual precipitation)

Additional Stuff

- We can use UtilitiesCalc to perform utility functions such as classifying final yield, saving data, etc.

- First let's import UtilitiesCalc class

```
'''importing library'''

import UtilitiesCalc
obj_util = UtilitiesCalc.UtilitiesCalc()
```

Additional Stuff - Classifying final yield

- Classifying final yield and visualization

```
'''Classifying final yield'''

yield_map_rain3_class = obj_util.classifyFinalYield(yield_map_rain3)

'''visualize result'''

plt.imshow(yield_map_rain3_class)
plt.colorbar()
plt.show()
```

Additional Stuff - Saving File

- Saving File as GeoTiff file

- This function will copy geo-reference information from given GeoTiff file and save the numpy file as another GeoTiff file.

```
'''finally saving raster file'''

obj_util.saveRaster('./sample_data/input/LAO_Admin.tif',
'./sample_data/final_yield_rain.tif', yield_map_rain3)
```

Thank you !