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The Optimum Planting Time and Cropping Pattern of Potatoes and Other Horticultural Commodities based on Water Balance in Solok, Indonesia

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ABSTRACT

Many mountainous regions in Indonesia have been utilized for potato cultivation. But location for the cultivation is mainly a rainfed agriculture, which greatly depend on the weather condition. Lembah Gumanti in Solok, West Sumatra is a rainfed main potato-growing area, which faced a low productivity during dry season. Therefore, efforts to optimize potato production in rainfed area remains research challenge. This study aims to identify the optimum cropping calendar for potato and other horticultural commodities in Lembah Gumanti for 2018-2021. We used the water balance approach to derive daily water availability at field level. The approach was used to identify the planting time and pattern of potato and other horticultural commodities for 2018-2023 at dekadal (10-day) interval. The results showed that the most suitable planting time and cropping pattern varied annually. In 2018-2019, the cropping calendar was potato (in October 1st 10-day) – shallots (in April 1st 10-day) – chilies (in July 3rd 10-day). For 2020-2021, the best cropping calendar was shallots (in November 3rd 10-day) – potato (in March 3rd 10-day) – shallots (in August 1st 10-day). The findings reveal that water availability determined the cropping calendar of each commodity.

KEYWORDS
cropping calendar, dekadal interval, farming analysis, rainfed agriculture, water availability

INTRODUCTION

Potato is one of the main horticultural commodities in West Sumatra, especially in Solok Regency (Governor Regulation of West Sumatra, 2019). In 2020, from 700 hectares of potatoes in Solok Regency, it produced 14,283 tons of potatoes, which showed an increased production by 16.7% (Statistics Indonesia for West Sumatra Province, 2020). Yet, the production is still not sufficient to meet potato demand in West Sumatra (~33,672 tons).

Granola L. is a potato variety, which is widely planted in Solok. The yield potential for this variety is up to 10-30 tons per hectare, with an average of 26.5 tons per hectare (Indonesian Vegetable Research Institute, 2021). Therefore, there is a likelihood of increasing the yield by 4-6 tons for each growing season. To increase potato production, several options are available, such as expanding the crop area, streamlining cultivation management, or increasing the planting frequency. Nowadays, based on Solok District Agriculture Office (2020), the potato planting index in Solok is 100. This value indicates that potato cultivation is only performed in one growing season on the same land within a year. Yet, the potato planting index had a prospect up to 300, which means more space to increase its production.

According to Nasir and Toth (2022), potatoes are highly sensitive to water stress. Water stress may lead to decrease in tuber yield and quality (Wagg et al., 2021). To obtain an optimum yield, the total available moisture content should be preserved by more than 50% (Zhang et al., 2021). In rainfed fields, it is crucial to match the potato cultivation according to the crop calendar to minimize the risk of decreasing production.

The Ministry of Agriculture Republic Indonesia, through the Agricultural Research and Development Agency has developed an information system of crop calendar for rice, maize, and soybean since 2014. In 2016, the Center for Horticultural Research and Development began constructing a crop calendar for horticultural crops mainly focusing on shallots (Sarvina, 2019; Pramudia and Puspita, 2017). Therefore, there is an opportunity for developing crop calendar for other horticultural commodities, such as potatoes.

Adjustments to the time and pattern of potato planting can be calculated using the water balance method (Thornthwaite and Mather, 1957). This method utilized climatic variables including rainfall and temperature information per ten-days (dekadal). This information is required to calculate the availability of soil water content in the soil, during surplus and deficit conditions. Water balance method has been widely used for calculating domestic water demand in watershed areas (Putri and Perdinan, 2018), identifying root macroscopic parameter (Hupet et al., 2002), analyzing land water balance (Widodo and Dasanto, 2010), as well as analyzing crop water requirements based on their growth phase (Sirait et al., 2020; Setiobudi and Sembiring, 2009). After the calculation, the result is used as the basis for determining the optimum planting time and cropping pattern to achieve maximum potato production. This study aims to determine the most suitable planting time for potato field and other horticultural commodity based on water balance to achieve optimum production.

RESEARCH METHODS

Data Source

The research was conducted from October 2021 to July 2022 in the main potato-growing area in Lembah Gumanti District, Solok Regency. The data employed in this research consisted of primary data and secondary data from several sources. Water balance analysis and validation of the crop calendar utilized data from Solok Agricultural Office. Rainfall data from 2007-2021 was obtained from Kembar Lake Station from Water Resources Management Office of West Sumatra. Reanalysis data of mean, maximum, and minimum air temperature from 2019-2021 and humidity, radiation also wind speed data from 2018-2021, which were the input for potential evapotranspiration (ETp) calculations was obtained from NASA Power (https://power.larc. nasa.gov/data-access-viewer/).

Climate projection data of rainfall and temperature from 2022-2023 was obtained from CMIP5 with output model MIROC5, using scenario of RCP 4.5 (https://esgf-node.llnl.gov/search/esgf-llnl/). The rain projection data was bias corrected, using the method described by Weiland et al., (2010), so it can be used as input in the calculation of the water balance. Crop coefficients during all growth phases was obtained from FAO (Allen et al., 1998). Data of pF curve in 2022 was obtained from laboratory analysis results. Lastly, total planted area, harvested area, and potato production from 2019-2021 were obtained from Solok Agricultural Office.

Farmers Survey

Survey on the existing cropping system management was carried out by structured interviews with a purposive sampling. As many as 50 respondents from three villages in Lembah Gumanti were assigned to the areas with the largest potato planting area. Descriptive analysis was then performed to construct existing crop calendar and cropping patterns at the research site.

Water Balance Analysis

The determination of potato planting time utilized water balance analysis and crop water requirements in each growth phase. The initial phase of each commodity lasts for approximately ten to twenty days (Danielescu et al., 2022; Salwati, 2015; Supriadi et al., 2018), and this condition becomes the basis for calculations in ten-days (dekadal) period. The water balance analysis was based on the climate variables, Thornthwaite and Mather method.

To carry out the analysis, information was req-uired including the mean air temperature and average dekadal rainfall. Soil properties such as water holding capacity was obtained from soil layers at 15 and 30 cm depth from the depth of soil section, field capacity and permanent wilting point was derived to identify the water holding capacity. Water holding capacity was calculated using Equation 1 (Hengl et al., 2014; Monteiro et al., 2018).

$$\mathrm{WHC} = \sum_{i=1}^{n} (\mathrm{FC_i} - \mathrm{PWP_i}) \times \mathrm{Z_i} \quad (1)$$

Afterwards, the water balance analysis procedure in Microsoft Excels was performed as follows:

1. Column 1: Dekadal rainfall.
2. Column 2: Plant growth phase.

3. Column 3: Potential evapotranspiration (ETp) was calculated using Penman-Monteith (Allen et al., 1998) method with formula showed in Equation 2.

$$\mathrm{ETp} = \frac{0.408\Delta(R_n - G) + \gamma(\frac{900}{T+273})u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

4. Column 4: Crop coefficient (Kc) referred to FAO Article No. 33 (Doorenbos and Kassam, 1979).
5. Column 5: Crop evapotranspiration (ETc), which was equivalent to crop water requirement was calculated using Equation 3.

$$\mathrm{ETc} = \mathrm{Kc} \times \mathrm{ETp} \quad (3)$$

6. Column 6: Difference between rainfall and ETc.
7. Column 7: Accumulated potential water loss (APWL) was calculated using Equation 4.

$$\mathrm{APWL} = \begin{cases} = 0 & , \text{if } \mathrm{rf} - \mathrm{ETc} \geq 0 \\ \sum|\mathrm{rf} - \mathrm{ETc}|_{\mathrm{neg}} & , \text{if } \mathrm{rf} - \mathrm{ETc} \leq 0 \end{cases} \quad (4)$$

8. Column 8: Available water capacity (AWC) was calculated using Equation 5.

$$\mathrm{AWC} = \mathrm{WHC} \times (1.0004124 - \frac{1.073807306}{\mathrm{WHC}})^{|\mathrm{APWL}|} \quad (5)$$

9. Column 9: Available water capacity change (DAWC) was calculated using Equation 6.

$$\mathrm{DAWC} = \mathrm{AWC_i} - \mathrm{AWC_{i-1}} \quad (6)$$

10. Column 10: Actual evapotranspiration (ETa) was calculated using Equation 7.

$$\mathrm{ETa} = \begin{cases} = \mathrm{ETc} & , \text{if } \mathrm{rf} > \mathrm{ETc} \\ = \mathrm{rf} - \mathrm{DAWC}, & \text{if } \mathrm{rf} < \mathrm{ETc} \end{cases} \quad (7)$$

11. Column 11: Soil Water deficit was calculated using Equation 8.

$$\mathrm{Defisit} = \mathrm{ETc} - \mathrm{ETa} \quad (8)$$

12. Column 12: Soil Water surplus was calculated using Equation 9.

$$\mathrm{Surplus} = \begin{cases} = 0 & , \text{if } \mathrm{rf} - \mathrm{ETc} < 0 \\ = \mathrm{rf} - \mathrm{ETc} - \mathrm{DAWC}, & \text{if } \mathrm{rf} - \mathrm{ETc} > 0 \end{cases} \quad (9)$$

Table 1. Acronym description.

Acronym	Explanation	Unit
WHC	water holding capacity	mm
FC	Soil suction volume at field capacity	mm/10days
PWP	Soil suction volume at permanent wilting point	mm/10days
i	The number of soil layers	
n	Total soil layer	
Z_i	Depth of soil layer	cm
R_n	Net radiation	MJ/m^2/day
G	Ground heat flux density	MJ/m^2/day
Q	Average daily air temperature at 2 m height	^{0}C
u_2	Wind speed at 2 m	m/s
e_s	Saturated vapor pressure	kPa
e_a	Actual vapor pressure	kPa
$e_s - e_a$	Saturated vapor pressure deficit	kPa
Δ	Vapor pressure slope curve	kPa/^{0}C
γ	Psychometric constant	kPa/^{0}C
ET_o	Reference evapotranspiration	mm/day
ETc	Crop evapotranspiration	mm/day
ETp	Potential evapotranspiration	mm/day
K_c	Crop coefficient value	
rf	Rainfall	mm
π	Profits obtained by farming households after applying the planting calendar for cultivating potatoes, shallots and chilies in one growing season	IDR
TR	Total income earned by farming households after applying the planting calendar for cultivating potatoes, shallots and chilies in one growing season	IDR
tc	Total costs incurred by farmers in cultivating potatoes/shallots/chili peppers in one growing season	IDR
P	Commodity prices at the producer level at the time of harvest	IDR/Kg
Q	Total production of planted commodities	Kg
TFC	Total Fixed Cost, namely costs incurred by farmers that do not affect output/production results	IDR
TVC	Total Variable Cost, namely costs whose magnitude changes in the direction of changes in the amount of output produced	IDR

The potato planting time was based on a graphical analysis from rainfall, soil water availability, actual evapotranspiration, and soil water deficit and surplus. Also, it was determined based on the initial period when field capacity and crop water requirements were met within the growth period.

Planting time validation was carried out by comparing existing crop calendar at the farmers level with the planting time from water balance. The parameters used for validation were planting schedule, planting area, harvested area, yield and farming analysis. The planting schedule, planting area, harvested area and yield were used to identify any decrease in the initial planting area compared to the harvested area. Farming analysis was important to find the most suitable planting time and cropping pattern, that can provide optimal profit for farmer households. The farming analysis was using Equation 10-13 (Soekartawi, 1995).

$$\pi = \mathrm{TR} - \mathrm{TC} \quad (10)$$

$$\frac{\mathrm{R}}{\mathrm{C}} = \frac{\mathrm{TR}}{\mathrm{TC}} \quad (11)$$

$$\mathrm{TR} = \mathrm{P} \times \mathrm{Q} \quad (12)$$

$$\mathrm{TC} = \mathrm{TFC} + \mathrm{TVC} \quad (13)$$

The R/C (Return Cost Ratio) was a comparison of total revenue to total expenditure (cost). The R/C analysis was an analytical tool aimed to measure the efficiency of a farming practices. The R/C value of horticultural crop cultivation in this analysis was the efficiency of crop cultivation in each growing season. If the value of R/C > 1, the farming practices was considered efficient. On the other hand, if the R/C value < 1, then farming was inefficient or detrimental (Soekartawi, 1995; Zulkarnain et al., 2022). Description of the acronyms used in the equation were in Table 1.

RESULTS AND DISCUSSION

Climate Characteristics in Lembah Gumanti District

The rainfall pattern in Lembah Gumanti District is an equatorial type (Salmayenti et al., 2017), with the wet period > 200 mm/month occurring for four months. The peak of rainfall is recorded in December and April, while the lowest rainfall period lasts three months from July until September (Figure 1a).

The average potential evapotranspiration (ETp) data in 2006-2021 (Figure 1b) based on the Penman-Monteith calculations show that the highest ETp were recorded in March and October. The ETp in Lembah Gumanti had the same pattern as the ETp in Sukarami, where the highest range occurs in the January-April and September-December (Nugroho et al., 2019). Under adequate water supply, evapotranspiration increases peak conditions until situation where soil water content dropped to PWP. Therefore, during this period if the intensity of rainfall was lower it will cause deficit in soil water content.

Existing Potato and Other Horticultural Commodity Planting Calendar

Generally, the land in Lembah Gumanti is far from water sources so that rainfall greatly important in every growth phase. The farmers in this area had a cropping pattern, which was sequentially potatoes - shallots - other vegetables (chili, tomatoes, cabbage, shallots, potatoes, and celery) and it periodically practice annually. Based on the survey results, the existing cropping pattern on farmer's land can be seen in Figure 2. The cropping pattern in 2019 was potatoes – shallots – chilies and potatoes – shallots – shallots for 2020-2021. This pattern followed the previous cropping pattern with consideration of market demand.

During survey period, the average productivity data for each commodity were 16 – 22 tonnes/ha (potatoes), 11 – 18 tonnes/ha (shallots), and 4.34 – 25.27 tonnes/ha (chili). These three productivities seem to fluctuate year by year. The better fluctuations in potatoes and shallots productions indicated that both commodities have adapted well to the climatic conditions during growth period. Meanwhile, the fluctuation of chili production was quite high, likely because this commodity was not sufficiently adapted to climatic conditions, which were quite dry in certain planting months.

Planting Calendar of Potatoes and Other Horticultural Commodities Based on Water Balance Analysis

The water balance calculation utilized rainfall, evapotranspiration, and soil water fluctuations data so it can be an alternative in adjusting the time and pattern of planting in rainfed land. In addition to the weather and soil water factors, the physical properties of the soil also influenced the rainfed land. In this research location, the land had a dominant texture of silt with an average pF of 2.5 (field capacity) of 53.2% and an average pF of 4.2 (permanent wilting point) of 36.8%. So that the soil water availability was 49.05 mm. The water balance analysis of potato, shallot, and chili cropland in 2018-2023 (Figure A2).

The results of the water balance analysis and the cropping calendar in the potatoes, shallots and chilies plantations in 2018-2023 showed that most of the soil water condition was in a surplus of water, except in November I-II 2018, March I – April I 2019, August III - September III 2019 , October I – November I 2019, March I-II 2020, July III – August I 2020, December I-II 2020, January III – February III 2021, October I – Nov-

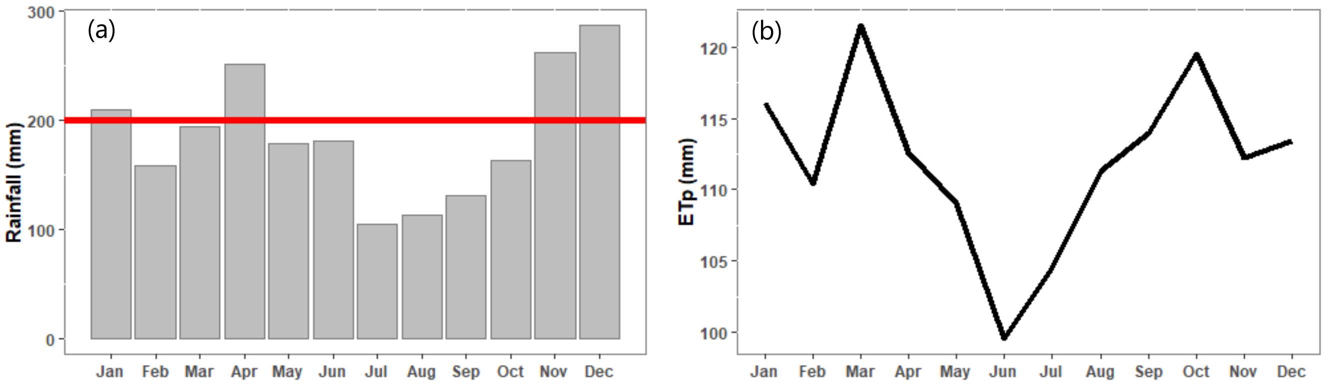

Figure 1. Average monthly: (a) rainfall (mm), (b) potential evapotranspiration (mm) of Lembah Gumanti District 2006-2021. A red horizontal line in part (a) indicates a threshold for wet period.

-ember I 2019, March I-II 2020, July III – August I 2020, December I-II 2020, January III – February III 2021, October I-II 2021, and November III – December I 2021. This happened because during that period the available soil water were in deficit condition as indicated by the average ten-day rainfall, which was lower than the average ten-day ETp, as shown in Table 1. Between these planting periods, the longest (around forty days) soil water deficit occurred in the period March I – April I 2019, August III – September III 2019, October I – November I 2019, and January III – February III 2021.

This condition caused a decrease in available soil water content that closed to the permanent wilting point for potato, shallot and chili plants as shown in Figure A2. In the condition, it was necessary to add irrigation water to prevent disturbance on the plant growth and development processes (Steduto et al., 2012). In the 2018-2020 planting year, it was necessary to plant them in a polyculture way to avoid dying, because prolonged deficit periods.

In dry conditions, the polyculture cropping system was better because it was more profitable for farmers, as practiced by Lombok farmers (Akhmad, 2021). Potatoes planted in the intercropping system may obtain better profits compared to monocultures on the same area, such as in the Bandung area (Tinaprilla and Nugraheni, 2022). Meanwhile, in the 2019–2021 period, plants can be grown both in monoculture or polyculture (Figure 2). Therefore, the recommended planting calendar based on water balance calculations (Figure A1).

Based on the planting calendar farmers were given the choice to plant based on the availability of soil water, either in monoculture or polyculture ways. In 2018-2021, the condition of the land were suitable for growing potatoes, shallots, and chilies all year around, except on periods of soil water deficit when water availability decreases by more than 50% permanent wilting point, such in November I-II 2018, March I – April I 2019, August III - September III 2019, October I – November I 2019, March I-II 2020, July III – August I 2020, December I-II 2020, January III – February III 2021, October I- II 2021 and November III – December I 2021 (Figure A2).

However, farmers can continue planting during these times as long as they can provide more maintenance efforts, such as watering the plants. Meanwhile for temperate climates, the best cropping pattern was paddy – fallow – pulses. In addition to determining cropping patterns, the past research in East Java by Tsuchihashi and Goto (2008), it is possible to produce sweet sorghum throughout the year, but also partially by ratooning during the most severe drought period of the dry season (August and September). In the dry season on dry land, it was necessary to carry out integrated planting (polyculture) in order to minimize losses to farmers (Furqan et al., 2019).

After validation by adding farming parameters the optimum planting calendar recommendations were obtained as shown in Figure A1. It can be seen that by following the adjustment to the results of the water balance, especially during dry period, shifts in time and cropping patterns, can reduce the decrease in harvested area and increase profits for farmers in the 2018-2019 and 2019-2020 planting periods. The R/C values for the past two years were higher than the existing patterns by farmers, namely 3.3 and 3.4 respectively. However, in wet periods such as 2020-2021 and 2021-2022, the calculation of the water balance had not shown an improvement in production, yet the R/C value was higher than the existing pattern, namely 3.4 and 2.6.

In the 2021-2022 period it would be better if planting was carried out in a polyculture way as was the case with the existing farmers patterns. Thus, the recommendations for the best planting schedule in the 2021-2022 and 2022-2023 periods were shallots (December I) – potatoes (April II) – shallots (August III)

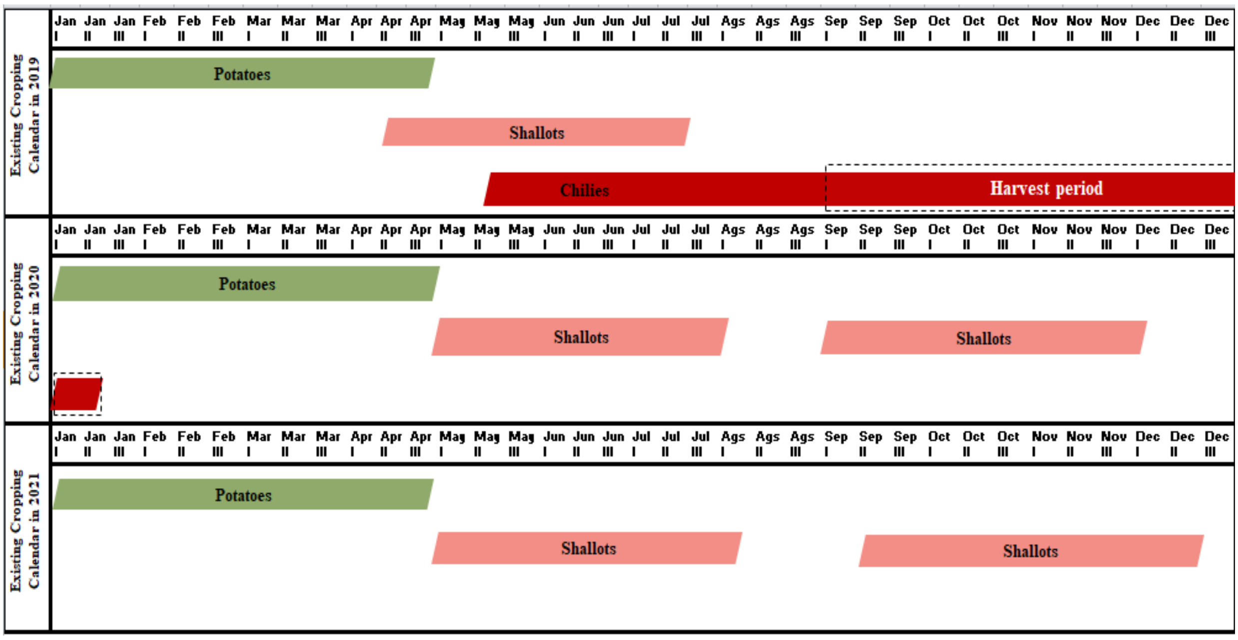

Figure 2. Diagram of the existing planting calendar for potatoes, shallots and chilies for 2019-2021.

Table 2. The average amount of rainfall and ETp based on the deficit period 2018-2021 planting year.

Planting Period	Rainfall (mm/10 days)	ETp (mm/10 days)
2018-2019	0,5 - 15	39,1 – 40,7
2019-2020	5 – 13	36,4 – 39,8
2020-2021	0 - 25	31,4 – 41,2
2021-2022	6,5 – 15,5	36,7 – 38,3

respectively, followed by the shallot planting pattern (December III) – potatoes (April II) – shallots (September I-II), with monoculture planting. Based on the water balance, it was predicted that 2023 will still be a wet period, so it was recommended to plant in polyculture by integrating chili and shallots while potatoes were planted in monoculture.

The results of this RC analysis were in line with the results of research by (Saputra et al., 2017), which reported that planting red potatoes in Sungai Nanam, Solok Regency in the middle of the rainy season (January - February) provides a 196% profit. In this case, it can be concluded that the basis for selecting commodities for crop rotation in a year was the water need and adequacy, economic benefits, and other considerations such as market demand and government policies (Makarim and Mejaya, 2017).

CONCLUSIONS

Based on water balance analysis for 2018 – 2023, the soil water conditions are sufficient for planting potatoes and other commodities throughout the year, except during deficit periods (e.g., August III - November I 2019). Its validation results with farming parameters, the best planting time and pattern were potatoes (October I) – shallots (April I) – chili (July III) in 2018-2019; potatoes (March III) – chilies (July II) – shallots (July III) in 2019-2020; shallots (November III) – potatoes (March III) – shallots (August I) in 2020-2021; shallots (December I) – potatoes (April II) – shallots (August III) in 2021-2022; and shallots (December III) – potatoes (April III) – shallots (September I-II) in 2022-2023, both monoculture and polyculture. Shifting planting schedules and cropping pattern adjustments need to be made so that farmers can get the highest benefits. In addition to considering the needs adequacy of water, as well as the commodities selection in crop rotation, it is also necessary to consider aspects of economic benefits, market demand, or government policies.

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ANNEX

Figure A1. Planting calendar from water balance analysis results for 2018-2023

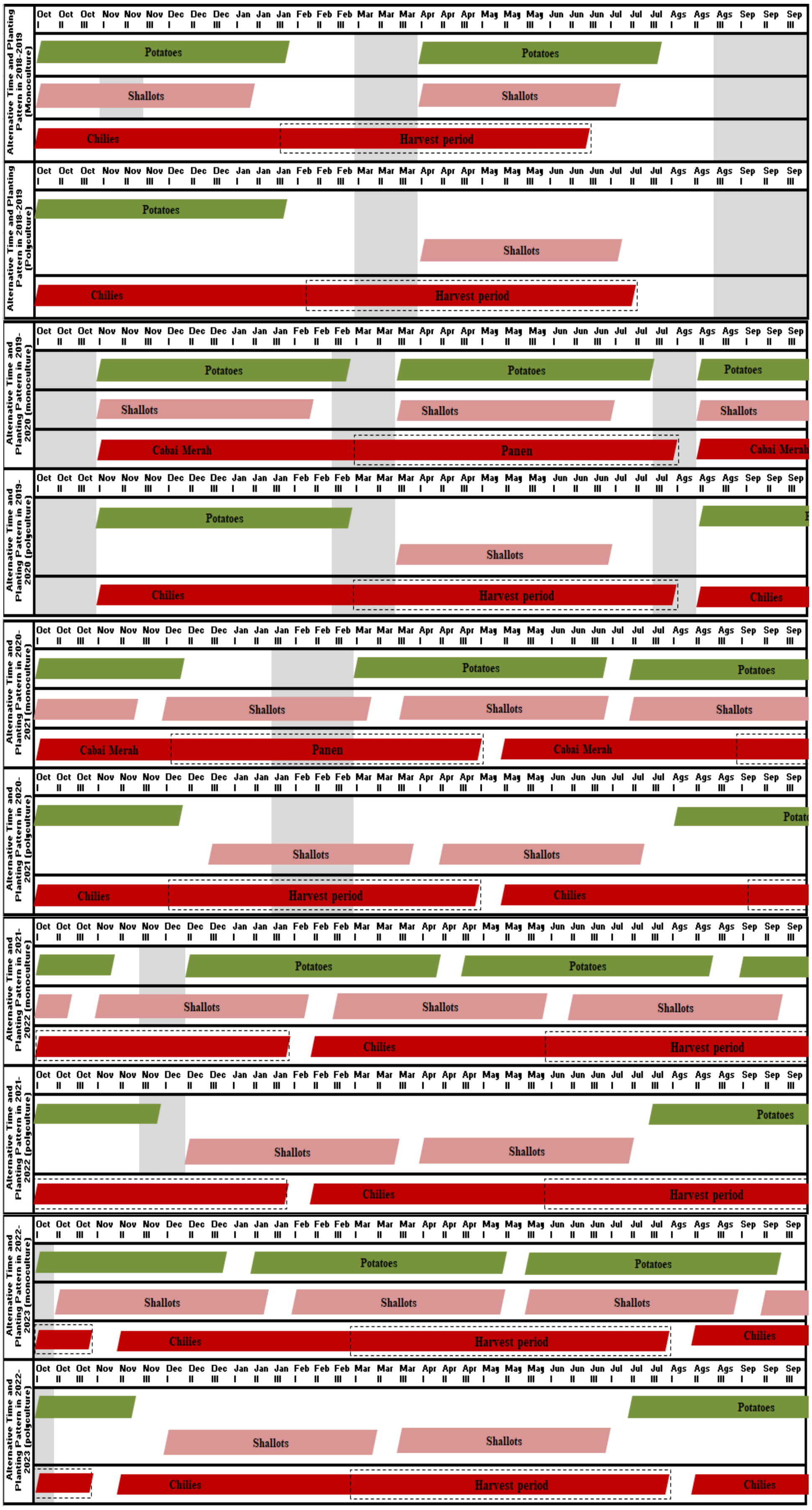
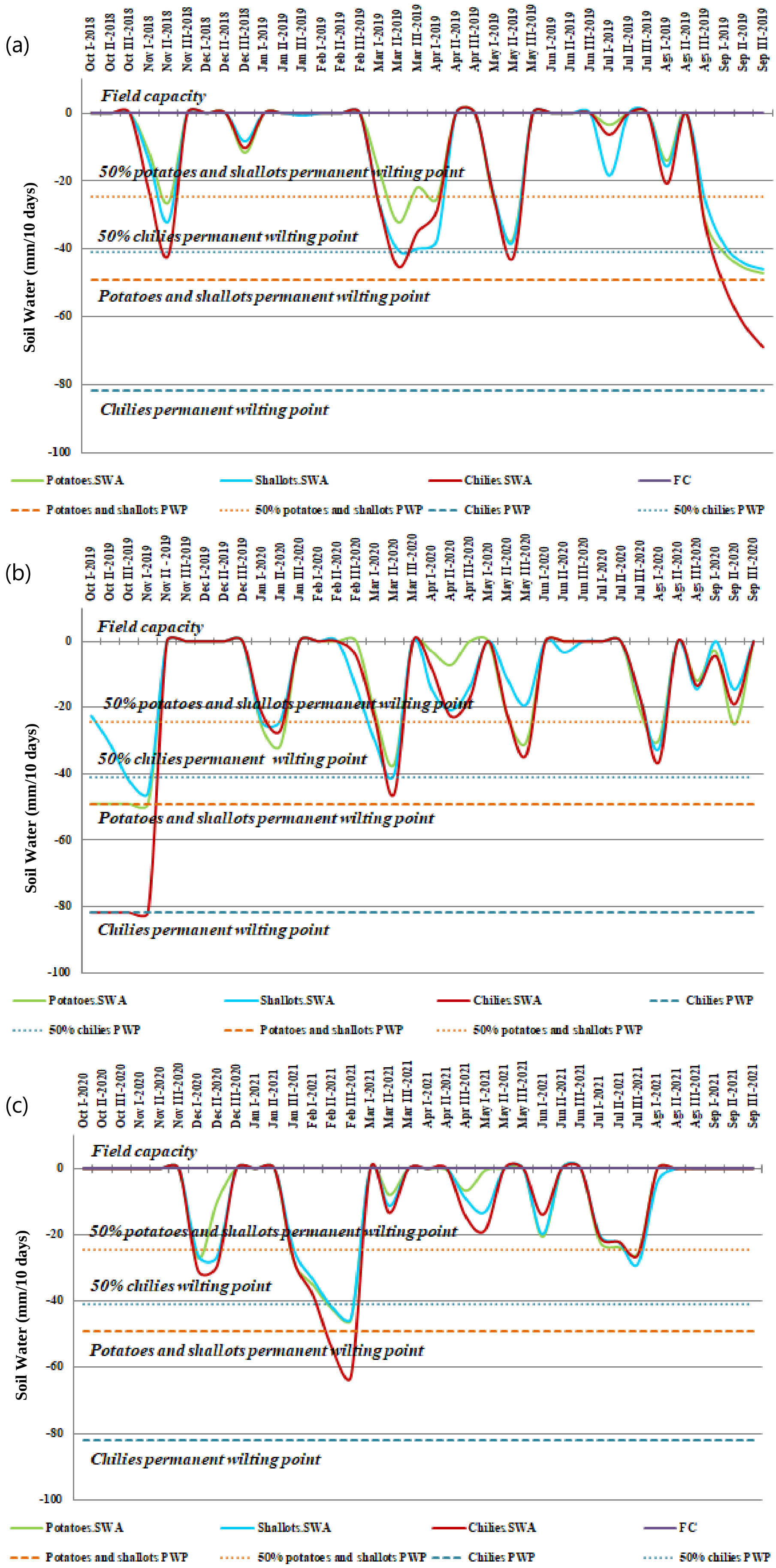
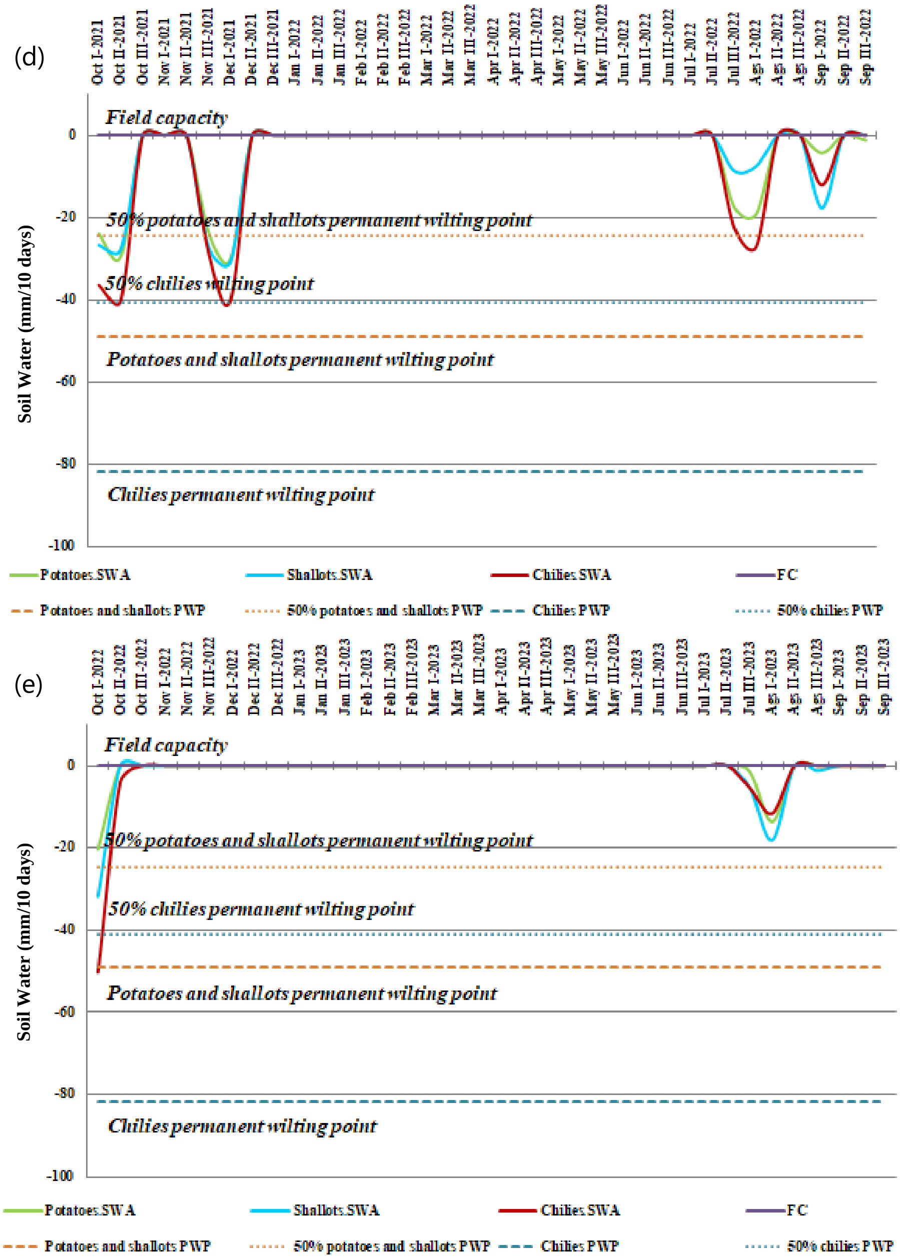


Figure A2. Decreased soil water content availability of potatoes, shallots, and chilies in: (a)2018-2019, (b) 2019-2020, (c) 2020-2021, (d) 2021-2022, (e) 2022-2023




(d)
Field capacity
50% potatoes and shallots permanent wilting point
50% chilies wilting point
Potatoes and shallots permanent wilting point
Chilies permanent wilting point
Soil Water (mm/10 days)
0
-20
-40
-60
-80
-100
Potatoes SWA
Shallots SWA
Chilies SWA
FC
Potatoes and shallots PWP
50% potatoes and shallots PWP
Chilies PWP
50% chilies PWP
(e)
Field capacity
50% potatoes and shallots permanent wilting point
50% chilies permanent wilting point
Potatoes and shallots permanent wilting point
Chilies permanent wilting point
Soil Water (mm/10 days)
Potatoes SWA
Shallots SWA
Chilies SWA
FC
Potatoes and shallots PWP
50% potatoes and shallots PWP
Chilies PWP
50% chilies PWP