The role of climate and agronomic practices on white asparagus production: possible consequences of climate change over French production

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Abstract

Climate influences plant phenology, thus playing a key role in defining growing seasons, harvest dates and the geographical range of crops. Quantifying the role of temperature and foreseeing the impact of climate change on crops is essential to inform farmers and politicians, to guide the agronomic practices and the adaptation to new climatic conditions. To this end, we propose and use a phenological process-based model to assess the dependance of asparagus (*Asparagus officinalis*) physiology on air temperature. The model explicitly accounts for the fact soil temperature, depending itself on previous weeks air temperature, determines the breaking of the winter dormancy, the plant growth rate and eventually the date at harvest. We demonstrated the model capability to estimate the harvest date against a 7-year data of harvest date and temperature time series from Nouvelle Aquitaine. We used the model to foresee the effect of predicted climate change over continental France under two IPCC scenarios (i.e. 4.5 and 8.5) and two time horizons (2041-2050 and 2091-2100). We foresee a shift north forward of the sites where asparagus cultivation will be possible and an anticipation in the harvesting dates. Our study provides novel insights for understanding and forecasting climate change impacts on asparagus phenology and it is the first framework that maps the ecological thermal niche of asparagus at a national level.

1. Introduction

Temperature is a well-known driving force of plant physiology thus determining for a given cultivar i) the possibility for cultivation and ii) the growing period and consequently the harvest time. Perennial plants in temperate regions often experience a winter dormancy induced by the decrease of photoperiod and low temperatures. Dormancy usually involves three phases: dormancy induction, endo-dormancy, and eco-dormancy (Fadón et al., 2020). Dormancy induction leads to leaves fall. Exposure to chilling is necessary to overcome endo-dormancy and eventually exposure to higher temperatures is necessary to escape eco-dormancy and start the vegetative season. Dormancy permit perennial plants to cope with possible damages of freezing temperature over bud burst processes. Once the necessary level of chilling has been overcome, the plant recovers progressively its capacity to grow. At this state, unsuitable temperatures prevent bud break. Buds require an amount of heat exposure to break, and the visible sign of growth appear after eco-dormancy break. However, the shift between endo-dormancy and eco-dormancy is not well defined. Also, Fadón et al. (2020) mentioned that "a long or intense period of heat can compensate for a lack of chill. Conversely, long, or intense exposure to chill can compensate for a lack of heat" (2020, p8). So, the length of endo- and eco-dormancy is not clearly defined.

In the present work we aim to **investigate the effect of climate and common agronomic practices on white asparagus** (*Asparagus officinalis*), an economically important perennial horticultural crop. Ku et al. (2008) studied the chilling needs of asparagus (Apollo variety) and they conclude that if the need for cold is not met, a significant delay is to be expected, with following warming temperatures below 15°C but no delay occurred with warming temperatures of 20°C or higher. They concluded that higher warming temperatures might compensate the delay due to the lack of chilling, which is in accordance with Vegis (1964). The main hormone involved in dormancy is abscisic acid (ABA). Its level increases through dormancy until enough chilling is accumulated and decreases (Wang et al., 2016). Gibberellin (GA) is known to play an antagonist role, promoting growth. We can understand from Nie et al. (2016) who measured Aba concentration through dormancy on asparagus, that lower the temperature of chilling, the shorter the time required for chilling.

In asparagus crops temperatures can be partially controlled by the usage of plastic covers on ridges. Plastic covers which can be black or white are intended to accelerate or slow down the vegetative growth to have the production peaks around the cultural consumption period, corresponding to the Easter period in Europe.

Moreover, climate shapes plant distribution and climate change is expected to disturb the actual pattern of geographic range of plants (Chuine, 2010, Lenoir et al., 2008, Vanalli et al., 2021). An issue previously cited on other crops is an insufficient winter chill (Delgado et al., 2021, Vanalli et al., 2021) due to rising temperatures in some areas. The most important area for asparagus production in France being in the mild-winter region Nouvelle-Aquitaine, insights on the asparagus geographical range can help anticipate economic consequences.

In the present work we address the following **questions**: 1) how temperature affects asparagus phenology and eventually harvest date?; 2) which is the efficacy of plastic covers in controlling underground temperature; 3) is the thermal niche of asparagus expected to shift due to predicted climate changes.

2. Material and methods

2.1. The study case: white asparagus production in France (physiology- phenology)

In temperate regions, when asparagus escape eco-dormancy, in late winter/early spring, the plant is completely underground and the spears, which will ultimately constitute the edible part of the plant, start growing from the underground buds. At the end of January, producers form the ridges (they earth up asparagus) and lay plastics to promote temperature increase. The buds are initiated, and the spears grow until they come out of the mound of soil where they are harvested at a length of 35cm. The buds are distributed by cluster on the roots, called the crown. There is an apical dominance per cluster, so that after the harvest of the first spear of a cluster, another bud is initiated. The harvest is done over about 60 days then the last spears grow until they become stems with cladodes.

From June to November, asparagus stems appear above ground and allow the plants to make photosynthesis and assimilate inorganic carbon to constate reserves for next season spears growth. At the end of autumn, asparagus start dormancy due to temperatures below 10°C (Ku et al., 2008), the stems are crushed. The crown is at 10cm below ground.

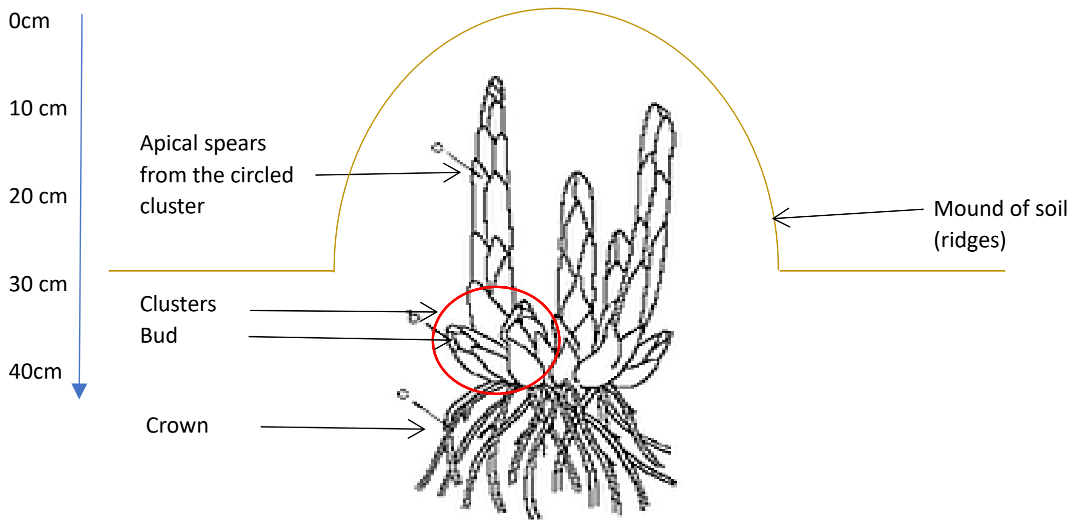

Figure 1: Asparagus crown and the spears development through a mound of soil made by producers (Minost C. www7.inra.fr)

Available material:

2.2. Data on asparagus yield production in France

We obtained asparagus yield in kilograms per day from 2015 to 2021 by the largest cooperative of Nouvelle-Aquitaine, representing 385 ha of asparagus production.

2.3. Data on temperatures (air and soil).

We obtained daily average air temperature and soil temperature at 10cm and 50cm, from 2014 to 2021, from a meteorological station at Saint-Martin-de-Hinx in the asparagus production area of Nouvelle Aquitaine. The data was provided by the INRAE CLIMATIK platform (https://intranet.inra.fr/climatik).

Soil temperature under black and white plastic of 200µm were provided by the cooperative (2019-2020) at a depth of 0cm (under the plastic). We used it with air temperatures from the station of INRAE at Onesse, in the same area as the soil temperatures.

2.4. *Predicted air temperatures in France*

We used predicted air temperatures from the DRIAS platform created by meteo-France (http://www.drias-climat.fr/). The data is a set of 120*122 points, resolution 8 km. Only the 8462 land points in mainland France are used. We used the hindcast temperatures with scenario Rcp 4.5 for the period 2010-2020. We chose the prediction in the 2040-2050 and 2090-2100 period under different IPCC scenarios: Rcp 4.5 and 8.5 (IPCC a, 2014).

Methods:

2.5. *A model to obtain* ***soil temperature*** *as a function of air temperature, soil depth and plastic cover usage.*

The plant biomass is belowground during the dormancy phase and the spear growing period. Assuming that processes are temperature based we assess a model to derive soil temperature as a function of past air temperatures and soil depth.

First, we estimated the effect of plastic cover by assessing temperature under the plastic cover (Ap) as a function of air temperature (A):

1) Ap = i*A+d

Second, we calibrated a model to estimate soil temperature as a function of previous air temperature and soil depth.

2) $Ts = minTs + \frac{(maxTs - minTs)}{1 + e^{-b*(Tef - lb)}}$

Where

$$T_{ef} = \frac{\sum_{t=t-n}^{T} (T(t))}{n}$$

Where *n* is the number of previous days affecting the soil temperature at a given day t. T is either the air temperature A or the air temperature under plastique Ap.

We chose the depth according to the month. From February to June, there is a mound of soil on asparagus. The crown is at 40cm, but we decided to take the depth of 20cm to consider the growth of the spear through the mound of soil. The rest of the year, the depth is 10cm.

2.6. Phenological models to estimate endo- and eco-dormancy break dates and peak harvest dates

Several models to determine the start and ends of different phenological phases, depending on temperatures, have been proposed for a number of plants. They are compared by Luedeling et al. (2009) and the Dynamic Model (Fishman et al., 1987) is the only one of these models to postulate that chilling occurs in a two phase process : the need of cold temperature followed by warmer temperatures. However, this model is more complex than the others. Chuine et al., 2016 offered more simple equations to assess this two-step process. They showed that endo-dormancy break in addition to eco-dormancy break should be parameters to be more precise. Regarding the dormancy phase of asparagus, we used the model of Chuine et al. (2016).

The state of chilling was the sum Sc(t) (Eq 4) of daily chilling rate Rc(Ts(t)) (Eq 3). When Sc(t) reaches a critical value C* (Eq 5), the chilling is satisfied. As understood from Nie et al. (2016), the lower the temperature of chilling, the shorter the time required for chilling. The equation is then:

3) $R_c(Ts(t)) = \frac{1}{1+(1+e^{a(Ts-T_c)})}$

4) $S_c(t) = \sum_{\xi=t_0}^{t} R_c(\xi)$

5) $S_c(t) = C^*$

The parameters for the equation were not available in the literature, therefore, hypothesizes have been made in accordance with experiments from the literature such as Nie et al. (2016) and Ku et al. (2008) papers. The parameter Tc correspond to the soil temperature when the asparagus gain 0,5 points of chilling (Rc(T(t)) = 0,5). It is hypothesized to be 6,26°C so that soil temperature at 10cm corresponds to 5°C in the air. Indeed, according to Nie et al. (2016) 2°C in the air performed better than 5°C in the air, therefore, 5°C cannot correspond to 1 point of chilling. "a" is set to 0,5 so that the chilling starts progressively under 10°C (Ku et al., 2008). Then, bud break is achieved once the sum Sf(t) (Eq 7) of daily rate forcing Rf(T(t)) (Eq 6) achieve another critical value F* (Eq 8). Tf is set at 13,68 °C so that at 20°C in the air, the forcing is very close to 1 because with higher temperatures than 20°C the forcing is the same (Ku et al, 2008). "s" is given the value 0,5 so that the start of the forcing is indeed between 4.8°C and 7.1°C (Wilson et al., 1999).

6) $R_f\left(Ts(t)\right) = \frac{1}{1+\left(1+e^{s\left(Ts-T_f\right)}\right)}$

7) $S_f(t) = \sum_{\xi=t_0}^{t} R_f(\xi)$

8) $S_f(t) = F^*$

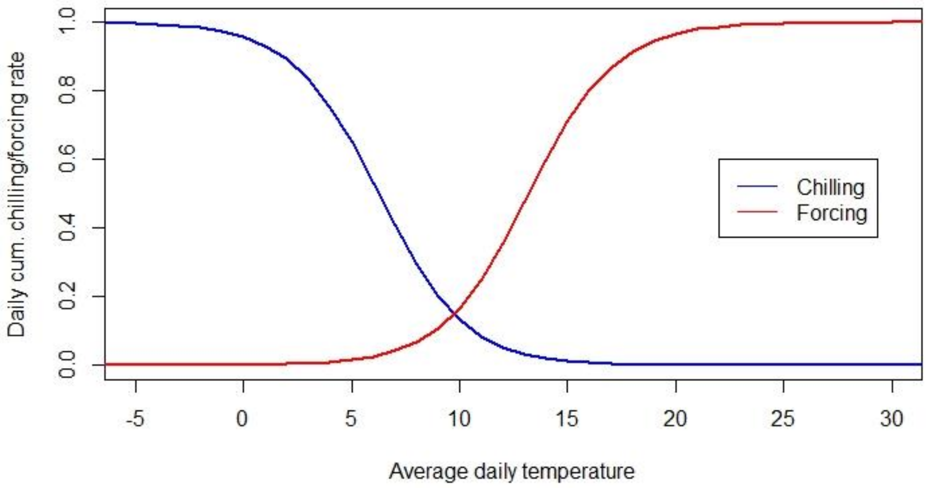

Figure 2 : Daily cumulative chilling and forcing rate according to the average daily temperature. The blue curve corresponds to the daily chilling rate Rc(Ts(t)) and the red to the daily forcing rate Rf(Ts(t)).

Growth initiation date is the date corresponding to Sf = F*.

Spear growth rate is influenced by temperature but also by spear length (Culpepper & Moon, 1939, Wilson et al., 1999). First, we assume that the relative spear growth Rgr is temperature dependent. According to Yan & Hunt (1999) we described it as.

$$9)\quad Rgr = R_{max}\left(\left(\frac{Ts-T_{min}}{T_{opt}-T_{min}}\right)\frac{\left(\frac{T_{max}-Ts}{T_{max}-T_{opt}}\right)^{T_{max}-T_{opt}}}{T_{opt}-T_{min}}\right)^{c}$$

The higher the temperature, the higher the rate of growth until the optimal temperature Topt, which was 33°C for Graefe et al. (2010). Tmax is set to be 41°C and Tmin to 4,8°C (Wilson et al., 1999).

Rmax is the maximum growth rate and is hypothesized to be 0,5 for asparagus. The last parameter c is responsible for the shape of the curve and is simplify to 1 by Yan & Hunt (1999).

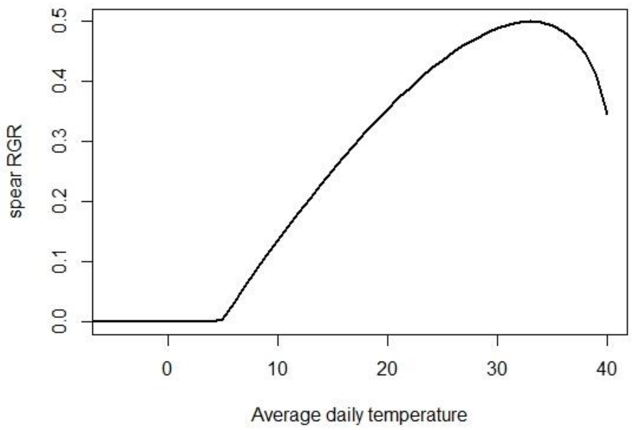

Figure 3 : The spear growth rate according to daily temperatures using Yan & Hunt (1999) equation of growth. Rmax = 0.5, Topt = 33°C, Tmax = 41°C, Tmin to 4,8°C and c=1.

Being temperature T time dependent, it follows that Rgr is time dependent itself.

From L(t+1) = L(t)*Rgr(t), one can easily derive

$$10)\ L(t) \quad = L_0 * \prod_{\xi=t_0}^{t} \left(1 + Rgr(Ts(\xi))\right)$$

To account for this, the spear length corresponds to Eq 10. L0 is set to 0,5cm (Graefe et al., 2010). The harvested length is usually 35cm.

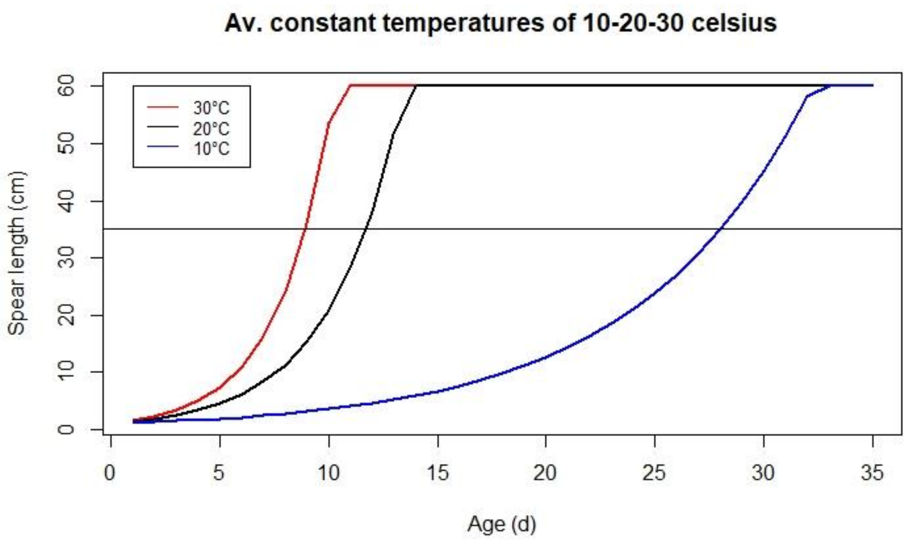

Figure 4 : The spear length according to the spear age in days, for three hypothetical constant temperatures: 10°C, 20°C and 30°C. The horizontal line represents the usual harvest length of white asparagus.

The phenological model runs through a life cycle corresponding to the 21st of September year N and ends the 20 of September year N+1.

We optimized C* and F* so that the estimated harvest of an average spear would be compatible with the peak of production. We used the “optim” function from R.

Equation	Parameter	Value	Source
Ap = i*A+d	I d	1.1 5.5	Calibration from data Calibration from data
$Ts = minTs + \frac{(maxTs - minTs)}{1 + e^{-b*(Tef - lb)}}$ $T_{ef} = \frac{\sum_{t=t-n}^{T} (T(t))}{n}$	Tmin Tmax n b lb	$0.05 * depth + 2.5$ $-0.05 * depth + 26.5$ $0.225 * depth + 7.75$ $0.000625 * depth + 0.21955$ *13*	Calibration from data Calibration from data Calibration from data Calibration from data Calibration from data
$R_c(Ts(t)) = \frac{1}{1 + (1 + e^{a(Ts - T_c)})}$	a Tc	0.5 6.26	Litterature Litterature
$S_c(t) = C^*$	C*	8.72	Calibration from data
$R_f(Ts(t)) = \frac{1}{1 + \left(1 + e^{s(Ts - T_f)}\right)}$	s Tf	0.5 13.68	Litterature Litterature
$S_f(t) = F^*$	F*	51.52	Calibration from data
$Rgr = R_{max}\left(\left(\frac{Ts - T_{min}}{T_{opt} - T_{min}}\right)\frac{\left(\frac{T_{max - Ts}}{T_{max} - T_{opt}}\right)^{T_{max} - T_{opt}}}{T_{opt} - T_{min}}\right)^{c}$	Tmax Tmin Topt Rmax c	41 4.8 33 0.5 1	Litterature Litterature Litterature Litterature Litterature
$L(t) \quad = L_0 * \prod_{\xi = t_0}^{t} \left(1 + Rgr(Ts(\xi))\right)$	L0	0.5	Litterature

Table 1 : Model equations and parameters with the specification of the source for the value. Litterature means that the value is an hypothesis in accordance with the literature.

2.7. *Thermal suitability maps*

We did a simulation on different Rcp scenarios (4.5 and 8.5) and periods of 10 years (2010-2020, 2040-50, 2090-2100). The Rcp scenarios come from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2014. We considered the plastic cover only when focusing on mapping Nouvelle Aquitaine (for the historic and near future) as producers' practices of plastic cover differ according to the area. Therefore, we decided to never consider cover on the France map. This choice allows a future addition of any type of plastic cover.

For a given life cycle, if eco-dormancy was not achieved by the 1st of March, the model returned that the area is too warm. If eco-dormancy was achieved, but endo-dormancy was not by the 1st day of September, the model returned that the area is too cold. Finally, if the spear did not obtain 35cm, the model returned that the area is too cold. If all the phenological steps were fulfilled, the model returns the estimated yield peak of this life cycle. For a point of the map, 10 estimated yield peaks are averaged. However, if at least one life cycle out of 10 could not fulfill all the phenological steps, the point took the value of that life cycle: "too warm area" or "too cold area". We believe there is no point of growing asparagus in an area where it might not be adapted.

3. Results

3.1. *A model to predict soil temperatures under plastic cover*

Regarding air temperature under plastic cover, the regression parameters were found to be i=1.1 and d = 5.5 with high significance for the t-tests (respectively, p-value =1.93e-06 and p-value < 2.2e-16).

3.2. A model to predict soil temperatures at different depth

We used the minimal and maximal temperatures from the observed data according to the depth (10cm and 50cm). From these values we built a linear regression to have the minimal and maximal temperatures for every depth:

$$11)\ minTs = 0.05 * depth + 2.5$$

$$12)\ maxTs = -0.05 * depth + 26.5$$

The number of previous temperature (nbmean) for the moving average were calibrated by optim to reduce SSE, at the same time as b and lb. The observed data being on a bare soil, we did not use the plastic cover regression. The parameter lb was found to be 13.1 regardless the depth. Nbmean and b are depth dependent.

$$13)\ n = 0.225 * depth\ +\ 7.75$$

$$14)\ b = 0.000625 * depth + 0.21955$$

Figure 5 shows a comparison between predicted and observed data. The function performed better at a depth of 50cm (SSE = 1228.68, mean error = 0.81°C) than 10cm (SSE = 2382.87, mean error = 1.17°C).

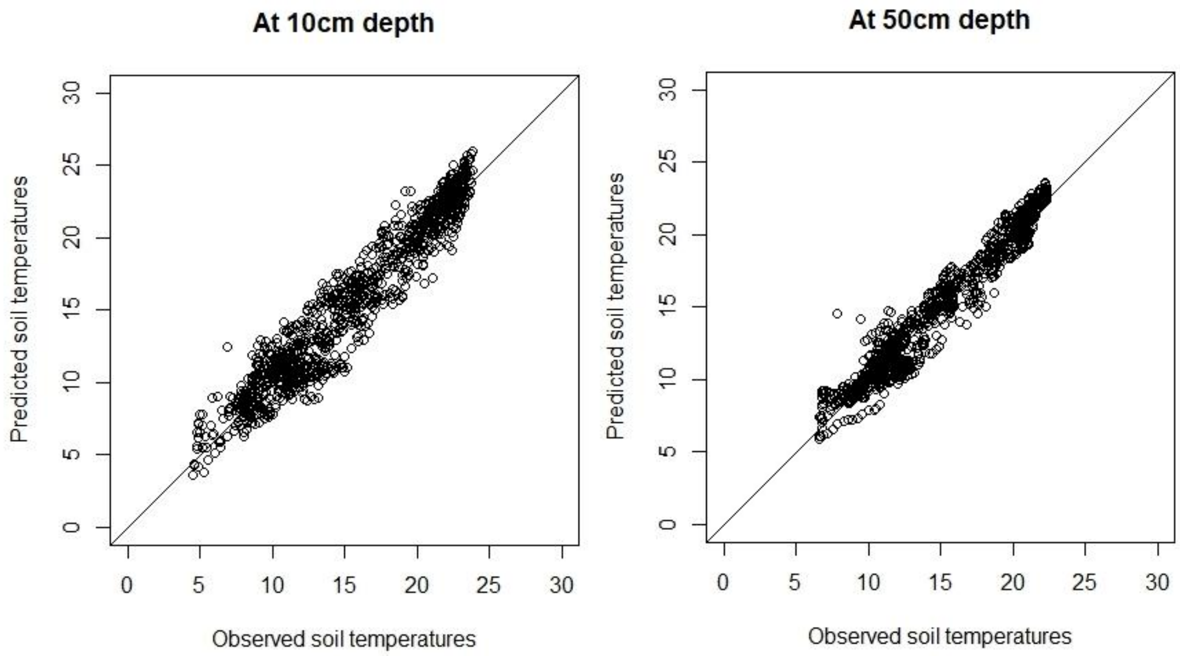

Figure 5 :Comparison between predicted temperatures from daily mean temperatures and observed temperature at depths of 10cm and 50cm. At 10cm, R^2 = 0.93, at 50cm, R^2 = 0.95. The sample has 1111 observations per variable (daily temperature, temperature at depths of 10cm and 20cm). The data was collected from the 01/11/2018 to the 22/11/2021.

3.3. Model performance on predicting harvest peaks

We calibrated the model to reduce the SSE between observed harvest peak and predicted harvest peak. We used plastic cover from the months 2 to 6 to fit producers' practices in Nouvelle Aquitaine. The critical values, for endo-dormancy break C* and eco-dormancy break F* were found by optimization to be C*=8.72 and F*=51.52. With these critical values, the mean error was of 5.83 days. Figure 3 show the predicted and observed day with the harvest peak for the year 2015 to 2021 (without 2020).

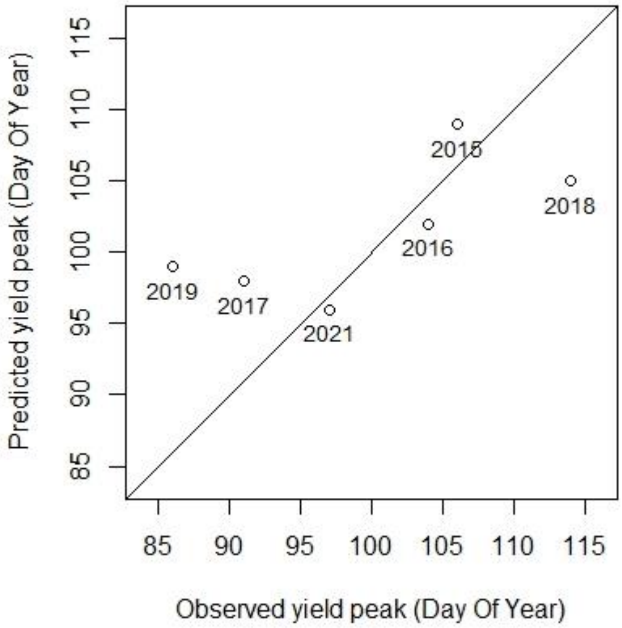

Figure 6 : Comparison between predicted and observed harvest peak in day of the year in Nouvelle Aquitaine. The mean error is 5.83 days, the maximum error is 13 days (2019) and the minimum error is 1 day (2021). R2 =0.41.

If we consider that the acceptable error is of 7 days, which is an interesting margin for producers, the model has a good fit for the years 2015 (3 days), 2016 (2 days), 2017 (7 days) and 2021 (1 day). The year 2020 is not represented as it is to consider with caution since it was a year impacted by covid-19 crisis. The producers prematurely stopped the harvest. However, the year 2019 (13 days difference) and 2018 (9 days difference), which are both extreme years in term of harvest time, are not well addressed by the model. Endo-dormancy break from 2019 (06/01/2019) arrived later than endo-dormancy break from 2018 (08/12/2017). However, 2019 might be very early because of a warm spring with a constant increase in temperatures. The temperatures for the harvest season of 2019 and 2021 are very similar and suggests the same production pattern. However, 2019 had an observed peak 11 days earlier than 2021. Producers indicates that ridges were made late January for 2019 but that late January 2021 was a rainy period and that ridges could only be built in February. This might be part of the explanation for the differences between these two years.

At the opposite 2018 spring had low temperatures which fluctuated a lot (declining lower than 0°C end of February). The parameters chose for the phenological equation, which are hypothesis, might be not reflect the response to very fluctuating weather.

3.4. Estimated maps of potential asparagus production in France in the next decades.

The first map predicted harvest peaks on historical temperature data, without considering the plastic cover as producer practices differ in France. The warmer areas such has southern Mediterranean coast have their harvest peak in late May without any plastic cover. The south coast of Nouvelle Aquitaine seems to have its peak beginning of June. Then, a major part of Nouvelle Aquitaine have its peak in mid-June. Northern, the harvest is in July and even end of July for some parts of Britany and Normandy. The mountains areas are well represented on the map as cold areas, having their harvest peak very late in summer, or even no production at all. Only one area is not suitable for endo-dormancy break. It is located on the Mediterranean coast around the one of the hottest cities of the metropolitan France: Toulon in the Var region.

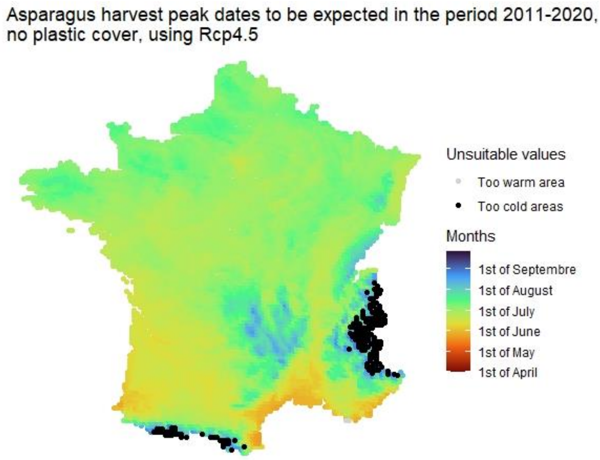

Figure 7 : Asparagus predicted harvest peak dates for the period 2011-2020, using RCP 4.5. No use of plastic cover. For each map cell (8 × 8 km2), the average value over the considered 10 years is reported. White map cell represents area where endo-dormancy break was not possible. Black map cell represents areas where eco-dormancy break was not possible or where the spear never grew up to 35cm.

The following maps are predictions of the harvest peak dates using 4.5 and 8.5 climatic scenarios. Scenario 4.5 is a moderate scenario with an average increase of 1.8°C (relative to 1986-2005) for the period 2081-2100. It predicts a moderate increase of extreme weather. Scenario 8.5 corresponds to an average increase of 3.7 on the same period with large increase of extreme weather. The near future France maps are in the appendix 1.

Far Future

(a) (b)

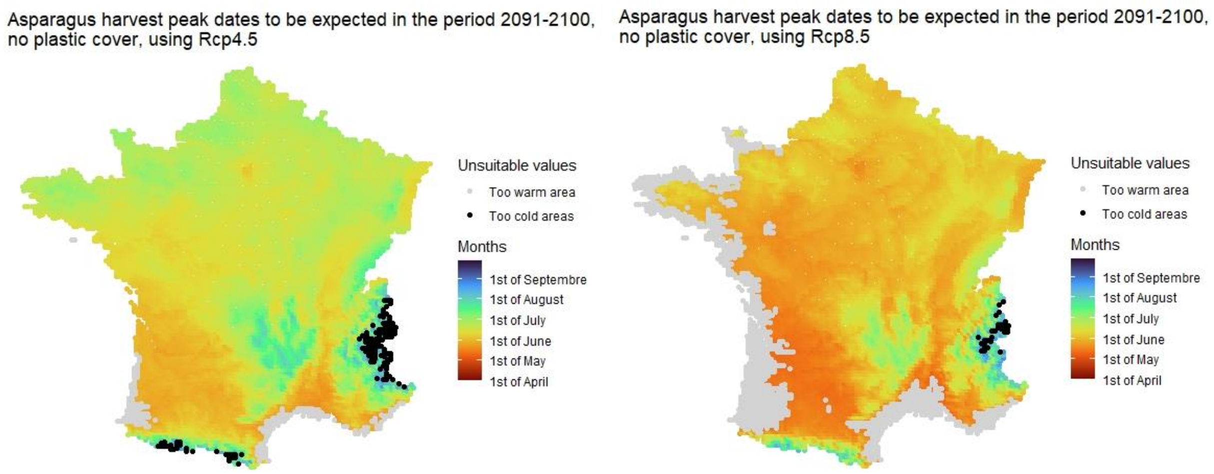

Figure 8 : Asparagus predicted harvest peak dates for the period 2091-2100, using RCP 4.5 (a) and RCP 8.5 (b). No use of plastic cover. For each map cell (8 × 8 km2), the average value over the considered 10 years is reported. White map cell represents area where endo-dormancy break was not possible. Black map cell represents areas where eco-dormancy break was not possible or where the spear never grew up to 35cm.

There is a very clear difference between predictions according to the scenario in the far future. With RCP 4.5, the mean difference with the historic is of 14.98 days (sd =2.62). Whereas with RCP 8.5 it is more than a month (33.98 days, sd=3.75). Nouvelle Aquitaine and Mediterranean areas are still the only areas with the impossibility of endo-dormancy break for RCP 4.5. However, these areas extend to land and not only coasts. For RCP 8.5, endo-dormancy break is not possible in large areas around the coast, even as north as Normandy, and we can see spots within the land. The actual first production area (Nouvelle Aquitaine) of white asparagus is mainly covered by white cells. Some areas in the mountains where eco-dormancy was not possible, have now a possible production in late summer in both scenarios. Scenario RCP 8.5 shows many cells with this situation, making production possible in the French Pyrenes.

Nouvelle Aquitaine with plastic cover

Plastic cover has been used on Nouvelle Aquitaine as the cover configured corresponds to the producers' practices of this area. In the model, the cover is set on the 1st of February as producers presently do.

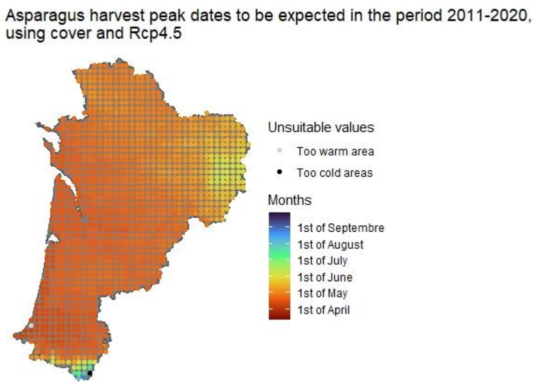

Figure 9 : Asparagus predicted harvest peak dates for the period 2011-2020 using RCP 4.5 on Nouvelle-Aquitaine. Use of plastic cover black and white. For each map cell (8 × 8 km2), the average value over the considered 10 years is reported. White map cell represents area where endo-dormancy break was not possible. Black map cell represents areas where eco-dormancy break was not possible or where the spear never grew up to 35cm.

Near Future

(a) (b)

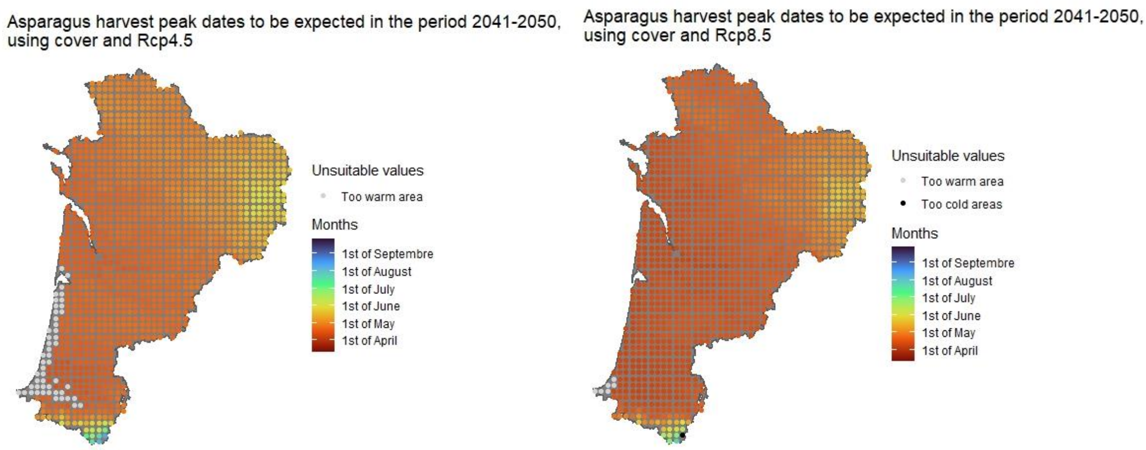

Figure 10 : Asparagus predicted harvest peak dates for the period 2041-2050, using RCP 4.5 (a) and RCP 8.5 (b). Use of plastic cover black and white. For each map cell (8 × 8 km2), the average value over the considered 10 years is reported. White map cell represents area where endo-dormancy break was not possible. Black map cell represents areas where eco-dormancy break was not possible or where the spear never grew up to 35cm.

In the near historic, the harvest peak is beginning of April. Only one cell in the south coast has no endo-dormancy break. However, in the near future RCP4.5, we can see many cells with no endo-dormancy break around the coast. Without cover, they are only a few in the very south (Appendix 1). This means that endo-dormancy break occurred in February, where the cover made it impossible because of its warming effect. For RCP8.5 endo-dormancy is also impossible at some places where it is possible without plastic cover (Fig8). There is still the difference of more white cells when using RCP4.5 for near future but the harvest peak dates are earlier with RCP8.5. The map for far future is not represented with cover as the producers might change practices in the far future.

4. Discussion

4.1. Asparagus present thermal areas

The model has a mean precision of 5.83 days, which could be considered good, according to the producers ‘cooperatives. However, extremes years in terms of harvest dates are not well considered by the model. The ridges construction dates might play a role and should be adapted for every year. The relation between air and soil temperature might be improved by implementing variables such as soil moisture, radiation, and wind strength.

Moreover, a validation on harvest data of another region could not be provided.

Chill accumulation is not known as a current issue for asparagus production areas in France. It is consistent with our results which suggests that this issue only appear around Toulon, which is not a production area for asparagus. Regarding mountainous areas, it is a lack of warm that prevent the fulfillment of either forcing requirements or growth. Our results being a simulation without plastic cover, it cannot be compared to producers yield dates, but we can see the most fitting regions for early production. National asparagus market promotes early production with a higher selling cost and according to the model, Nouvelle Aquitaine and Mediterranean regions seems to be the most fitting places for early production. It is currently the case, but they are not specialized in the same asparagus production: Nouvelle Aquitaine produce white asparagus where Mediterranean lands produce manly green asparagus. The model considers only white production. There is another large production areas of white asparagus in France which is Pays de la Loire. It has its harvest peaks a month later than Nouvelle Aquitaine on the maps.

Regarding green asparagus, they grow at the surface exposed to sunlight which triggers hormones. They do not have the same morphology as white asparagus (less diameter and fresh weight for example) (Siomos, 2018). The reserves might not be mobilized the same way and it might interfere with the growth rate. They are often cultivated in greenhouses where the temperatures to consider in the model should be the air temperatures in greenhouses. With this production system, the dormancy is induced by stopping irrigation in winter, leading to water stress. A model for green asparagus should include irrigation parameters to break dormancy.

The focus on Nouvelle Aquitaine shows harvest peaks beginning of April, when black and white plastic are used. Therefore, there is a month of difference with the use of plastic for this area. This assumption cannot be extended to other places as Nouvelle Aquitaine have the particularity of very sandy soils which allow an earlier formation of the ridge in the beginning of February. Indeed, sandy soils favor water infiltration, therefore, these soils rapidly get back to good conditions for field intervention. In other places with loamy and clay soil, the ridge can only be built later due to the need of dry condition.

4.2. Asparagus future thermal areas

According to our simulation, chill accumulation might become an issue for the near future in the Mediterranean area and the south of Nouvelle Aquitaine, for white asparagus. However, the damage seems to be limited to small areas. Harvest peak dates are expected to shift, according to the climatic scenario, from an average of 3,67 and 10.20 days earlier than the historic (Appendix 1).

Regarding, practices from Nouvelle Aquitaine producers, they might have to adapt the date for building ridge and use plastic cover. For that, they will need the model to give the date for endo-dormancy achievement before building the ridge. They could lose their advantage of earlier mound of soil and plastic cover by waiting the fulfillment of endo-dormancy.

Far future shows two very different maps according to the scenario chosen. We can see a necessary shift of production inside the land instead of production near the coast in RCP4.5. The pays de la Loire seems to have the harvest dates of the actual Nouvelle Aquitaine. Regarding scenario RCP8.5, harvest dates are all very early compared to the historic, even in the north. The decline in winter chill will become the major limitation for asparagus production in Nouvelle Aquitaine implying a radical change of the region production system. Rising temperature jeopardize winter chill for asparagus as reported for other crops (Delgado et al., 2021, Vanalli et al., 2021).

Shift in harvest peak dates are to be expected in a near future and with more strength in the far future. Asparagus is a seasoned vegetable for consumers. The cover practices to manage harvest dates will have to be adapted to these thermal changes. Beyond the changes of harvest dates, shift of the main region for asparagus production is to be expected in the far future.

4.3. Adapting to climate change and actual model limits

The actual model is built on many hypotheses of phenological parameters. Asparagus is a plant not often addressed by scientific research and there are only a few available data on its phenology. Therefore, endo-dormancy break should be evaluated for different temperatures by tracing hormones involved in the process such as the hormones ABA and GA (Liu & Sherif, 2019, Wen et al., 2016). Eco-dormancy break should also be determined by the observation of bud break and growth should be measured, with temperature as the control variable. Cultivars have usually different characteristics for dormancy release and growth development (Vanalli et al., 2021, Nie et al., 2016), therefore temperatures needs should be determined for every relevant variety. The two main varieties for white asparagus are Vitalim, an early cultivar, and Grolim, a mid-late cultivar. Vitalim could have less chill requirement than Grolim or less forcing requirement, or even both. Producers could adapt to the potential futur lack of chilling by selecting low chilling varieties. We also have to mention the induction of dormancy by lack of water. However, it would imply deep changes in white asparagus management in France. It is already done for small surfaces of green asparagus in green houses, but it would be a radical change for the actual large production of asparagus on open fields.

The model should be validated by datasets of harvest dates from different regions with different climates. Then, as mentioned, the model might be improved by using different cultivar parameters but also by including the partially compensatory relationship between the accumulation of chill and heat. The shift between endo-dormancy and eco-dormancy being not clear, models developed with clearly defined stages, as ours, might be inaccurate (Fadón et al., 2020). They may overestimate the critical values to reach to validate chill or heat satisfaction. They might not give the bare minimum. Only the parallel and alternative models from Kramer (1994) allow compensatory relationship.

5. Conclusion

Our study provided a model to assess harvest peak dates for asparagus. The model transforms air temperatures into soil temperatures at different depths before using phenological process of asparagus. It can give results without any cover or by applying black and white plastic from February to July. Other plastic types could be added to the model when their effect on air temperature on the top of the ridge will be determined. Our model can produce maps that allow the analysis of possible shifts of harvest peak dates due to climate change. Results implied that producers' practices might have to change in a near and far future. The accuracy of the model can help foresee the changes needed. Results also show the geographical shift of production due to a lack of chilling in winter. This shift intensity depends on the scenario used (RCP4.5 or RCP8.5). The model still needs to be validated with other regions' dataset of harvest peak dates. Research on the phenology of relevant asparagus cultivars should improve the model precision and accuracy.

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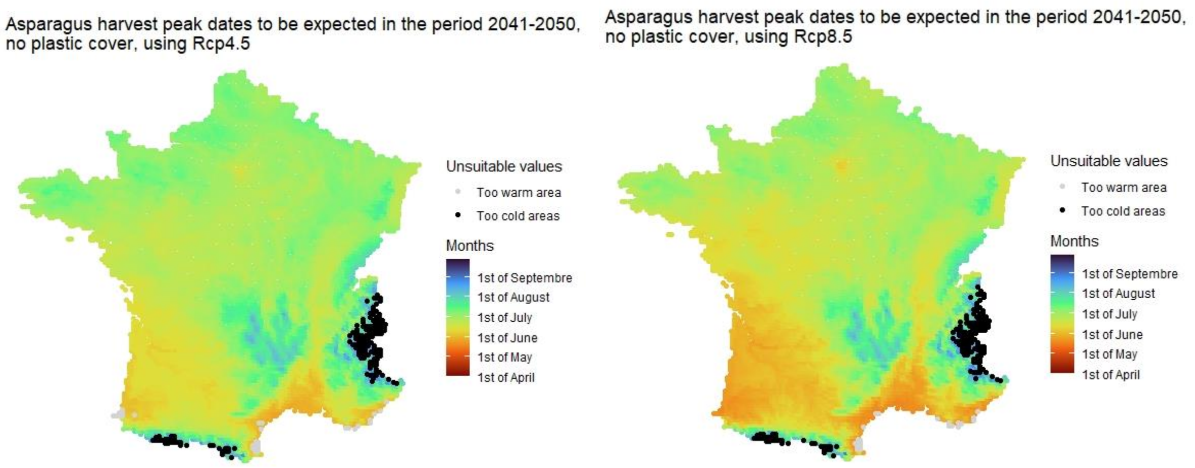
Appendix

Near Future

(a) (b)



Appendix 1: Asparagus predicted harvest peak dates for the period 2041-2050, using RCP 4.5 (a) and RCP 8.5 (b). No use of plastic cover. For each map cell (8 × 8 km2), the average value over the considered 10 years is reported. White map cell represents area where endo-dormancy break was not possible. Black map cell represents areas where eco-dormancy break was not possible or where the spear never grew up to 35cm.

Compared to the historic, the prediction using RCP 4.5 shows only small changes with dates that are a few days earlier (mean of day difference = 3.67, standard deviation (sd) = 1,50). In contrast, RCP8.5 already imply major changes with an average of 10.20 days earlier (sd = 3.45). RCP 4.5 and 8.5 scenarios suggest that some south areas might not be able to complete endo-dormancy in the period 2041-2050. However, they are not exactly the same in both predictions. RCP 4.5 prediction indicates a lake of cold in the south of Nouvelle-Aquitaine where RCP 8.5 does not, even if it globally indicates warmer springs.