Exploring Adaptation options to Climate Change for irrigated Rice in Africa

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1 Introduction

1.1 Background

Climate change will have an impact on future rice productivity. Van Oort and Zwart (2018) used the ORYZA2000 crop growth model (Bouman et al., 2001; van Oort et al., 2015a) to analyse the impact of 4 climate change scenarios for future rice production in Africa. In the most extreme scenario RCP8.5 for the year 2070 without adaptation, climate change impacts would be negative. In this scenario without adaptation projected yield decline was on average -21% for irrigated sites in East Africa and in West Africa (in the main season). In in irrigated rice in West Africa in the hot dry season projected yield decline was on average -45% with range between -4 (Senegal, coastal) and -80% (Mali, inland). This great variability is due to variation in sowing dates, variation in temperature (West Africa inland is hotter inland the coastal regions) and temperature rise (stronger temperature rise in the inland regions of West Africa). Based on these spatially variable results in the study by van Oort and Zwart (2018), sites for the current study were selected: 3 sites in West Africa (1 coastal, 2 inland sites) and 1 site in East Africa.

van Oort and Zwart (2018) considered one climate change adaptation option, i.e. a change in variety. Without adaptation the duration from sowing to maturity naturally becomes shorter due to rising temperatures and this in most cases causes a yield decline. They simulated the impact of switching to varieties with a lower development rate, such that in each site the number of days from sowing to maturity would remain the same as in the current climate. In the cooler sites of East Africa this adaptation has a strongly positive effect, while in West Africa often yield impacts remained negative, albeit much less negative than without this adaptation (from -45% to -15%). These findings call for a more encompassing search for adaptation options, more than only varietal changes. Other possible adaptation options hitherto not considered are (a) shifting sowing dates and (b) changing the number of rice crops per year (cropping intensity). The cropping calendar construction (CCC) tool developed by van Oort et al. (2016) potentially allows for analysing these three adaptation options (variety, sowing date, cropping intensity) and combinations of these options, such as for example simultaneously optimising the sowing dates of two rice crops and the variety used in this double cropping system.

1.2 Objectives

The objective of this study was to analyse and compare climate change impact without and with adaptation, considering three adaptation options: variety, sowing date and cropping intensity.

To achieve this objective, the following steps were taken:

1. Simulation of climate change impact and adaptation options for the current climate and one climate change scenario (RCP8.5 for the year 2000) for 4 sites in Africa;
2. Amend the CCC tool such that it can be used to study climate change scenarios;
3. Construction of all possible cropping calendars for the current and future climate, considering average crop durations and yields over 19 years, 36 sowing dates (10 days interval), 5 varieties (with different phenology), 5 crop rotations (single rice, double rice, rice-vegetable, rice-rice vegetable and triple rice) and different parts of the year blocked for vegetable cropping.

1.3 Limitations

1.3.1 Focus on adaptation options

Within the limited time for the project a methodological choice was made to spend most time on adaptation options, less on calibration and least time on different climate scenarios. In previous studies crop phenological parameters were estimated for popular varieties in Ndiaye and Fanaye sites in Senegal, one of which is also included in the current study (van Oort et al., 2011). A later study showed that the ORYZA2000 model, with the correct phenological parameters and with new heat and cold sterility equations could accurately simulate yields (van Oort et al., 2015a). Therefore, a limited calibration and validation was deemed to be sufficient. For the East African site, Ambohibary in Madagascar, there were no previous solid phenology calibrations and calibrations of the ORYZA2000 model. For Ambohibary we did therefore conduct a more elaborate calibration and sensitivity analysis. With regard to climate change scenarios a previous study already explored different time slots (e.g. 2030, 2050, 2070) and 4 different climate change scenarios (van Oort and Zwart, 2018). In summary, knowledge gaps are relatively small in terms of model calibration and climate change scenarios and relatively large in terms of adaptation options. This prompted us to focus on adaptation options. The current study shows how existing tools can be used to explore climate change adaptation options, considering in an integrated way Genetic and Management options in different Environments (G x E x M).

1.3.2 Varieties

Varieties may differ in tolerance to heat and cold (Dingkuhn et al., 2017a; Dingkuhn et al., 2017b) and this can be simulated with different heat and cold parameters in the input files of the model. In this study we focused on phenology because previous analyses showed phenology to be one of the main determinant of climate change impact (van Oort and Zwart, 2018) and because of lack of availability of well calibrated heat and cold parameters.

In the current study a baseline local popular variety was compared with 4 "in-silico" varieties, of which the phenological parameters were slightly modified from the baseline variety. An important question is whether these "in-silico" varieties are realistic. To test this, their phenology was compared with observed data from 80 varieties at 5 sowing dates at one of the study sites.

1.3.3 Yield gaps

Modelling was used to simulate potential yields. Potential means assuming no constraints of water, nitrogen, weeds, pests or diseases were simulated. In reality farmers often do not attain potential yields and the gap between actual yield and potential yield is called the "yield gap". Recently many studies have appeared on yield gaps in rice, including food security studies (van Oort et al., 2015b; van Ittersum et al., 2016; van Oort et al., 2017) and studies on causes of yield gaps (Tanaka et al., 2013; Tanaka et al., 2015; Niang et al., 2017; Tanaka et al., 2017).

We assumed actual yields respond in the same manner to climate change as potential yields. That is, if potential yields decrease by -20%, then we assume the impact will also be 20% for the actual yields. Therefore even if actual yields are less than potential, we believe still the <u>relative change</u> in potential yields can tell us about climate change impact. In many cases this is a plausible assumption. A possible exception is where scenarios indicate positive effects of climate change. A future higher yield means the crop will need more water and more nutrients. Existing yield gaps may in fact be caused by water or nutrient shortages, in which case it is questionable whether in the future more of these limited resources can be taken up by the crop. In line with this, scenarios by van Oort and Zwart (2018) showed smaller potential yield gains for rainfed rice than for irrigated rice. Because even if atmospheric CO_2 increases, rice would still be constrained by water availability in the rainfed systems. In these systems a combination of climate change, improved water management and improved fertiliser management can have the biggest impact. For irrigated environments a fair assumption is that ample water is available. And it is this reduced drought risks that makes investment in fertiliser less risky. One generally finds much higher fertiliser input levels in irrigated rice compared with rainfed rice. For this reason the results of the current study are relevant mainly for irrigated environments.

2 Materials and Methods

2.1 Sites

Adaptations to climate change were explored for 4 sites in key irrigated rice production areas in Africa. Figure 2.1 shows the sites in a map, Figure 2.2 compares weather in the 4 sites. Table 2.1 describes lists the sites and their climate zone according to the Köppen-Geiger classification (Kottek et al., 2006). Of the four sites, the Madagascar site is markedly cooler, has lower radiation levels and a higher annual rainfall (1504 mm/year over 1980-2010). The three West African sites experience their hottest period in April-May with temperatures occasionally exceeding 45°C. On average over the year Fanaye is the hottest and driest site (238 mm/year over 1980-2010). The highest maximum temperature of 47.4°C was reached in Niono on 2-June 1980. Cold is a problem in the highlands of Madagascar and it prohibits growing rice during part of the year, while even in the summer period cold can cause crop damage (van Oort, 2018). Cold can also be a problem in the three West African sites, when the period from panicle initiation to flowering occurs in January-February (van Oort et al., 2015a). Farmers can avoid this cold by picking appropriate sowing dates such that panicle initiation and flowering do not occur in this critical period (van Oort et al., 2016; van Oort, 2018).

Table 2.1 *Sites and climate zones.*

		Köppen-Geiger climate zone	
Country	Location	Acronym	Name
Madagascar	Ambohibary	Cwb	Warm temperate, winter dry, warm summer
Mali	Niono	BSh	Hot arid steppe
Nigeria	Kano	BSh	Hot arid steppe
Senegal	Fanaye	BWh	Hot arid desert

Figure 2.1 *Map of Africa and the 4 sites.*

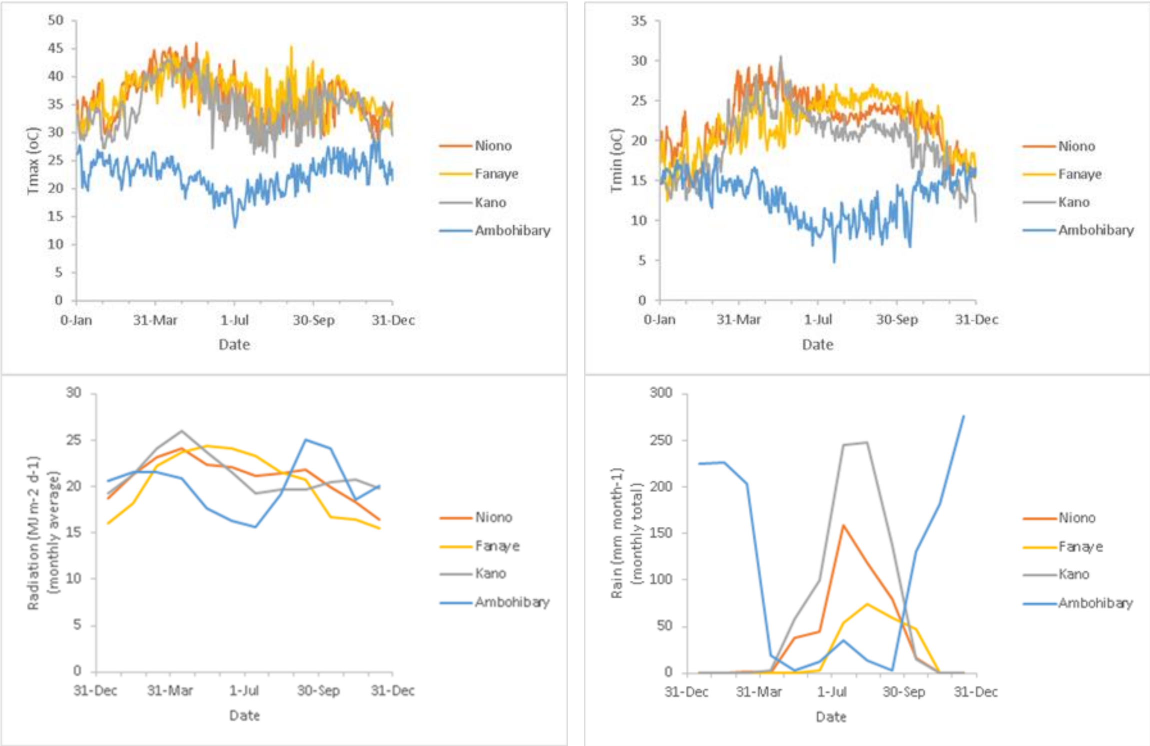

Figure 2.2 *Weather at the 4 study sites, year 2000.*

2.2 Crop growth simulations

2.2.1 ORYZA2000

Simulations were conducted with the ORYZA2000 model, version ORYZA2000v2n14s1 (van Oort et al., 2015a; van Oort and Zwart, 2018). For the Madagascar site an "East Africa" cold sterility equation was used, for the other three sites a "West Africa" cold sterility equation was used (Dingkuhn et al., 2017b; van Oort and Zwart, 2018). Simulations were for potential production, i.e. no constraints of water, nutrients, weeds, pests or diseases were simulated. For the current climate, simulations were made for the years 1991-2009 (average year 2000). For the future climate, the same 19 years were used but with different CO_2 level and with all daily T_{min} and T_{max} increased according to the climate change scenario (§2.3). Accurate modelling of the response of the duration of crop development phases is critical for accurate yield simulation, in the current climate (van Oort et al., 2011; van Oort et al., 2015a) and for the future (Zhang et al., 2016; van Oort and Zwart, 2018). ORYZA2000 simulates from emergence onwards. Here we additionally estimated the duration from sowing to emergence. In case of transplanting, ORYZA2000 simulates with a user-defined seedbed duration (SBDUR) and a transplanting shock (SHCKD) to model delayed development due to transplanting (Bouman et al., 2001). Below follows per site a description of how phenological parameters were estimated. Local cropping calendars and estimated phenological parameters and are shown in Tables 2.2 and 2.3.

2.2.2 Phenology calibration

Fanaye

In the Fanaye site we simulated with direct-seeding (local common practice), and a previously established relation between sowing date and duration from sowing to emergence (van Oort et al., 2016). In Fanaye the local popular variety is called Sahel 108. Sahel 108 parameters had been calibrated specifically by van Oort et al. (2011), using 15 sowing dates for 2 sites Fanaye and Ndiaye and data for these dates compiled by de Vries et al. (2011). Simulated duration from sowing to maturity was validated with more recently collected data from so-called rice-garden trials (RGT) conducted for 5 sowing dates in Fanaye in 2014-2015, results of which will be presented in this report.

Kano and Niono

For Kano and Niono we simulated with transplanting (local common practice). For these two sites a fixed duration of 4 days from sowing to emergence was assumed and a fixed seedbed duration of 28 days was assumed. Phenological parameters for the duration from emergence to maturity were calibrated using data on observed total duration and local common sowing dates were previously compiled in the GYGA project (www.yieldgap.org) (van Oort et al., 2015b; van Ittersum et al., 2016), complemented with more recent data compiled by AfricaRice. Cardinal temperatures of TBD= 14°C and TOD = 31°C were used, with no delay in development above TOD. Development rate for the grain filling phase (DVRR) was calibrated such that the 19-year average simulated duration from flowering to maturity would equal 30 days, the common duration for this phase (Vergara and Chang, 1985). After estimating the flowering and emergence date, development rates for the pre-flowering phases (DVRJ, DVRI and DVRP) were calibrated such that the simulated total duration from sowing to maturity would be close to observed total duration for the local popular variety at the local common sowing dates (Table 2.2). Parameters DVRJ, DVRI and DVRP were calibrated such that the period from panicle initiation to flowering would take 35% of the total time from emergence to flowering. No photoperiod sensitivity was assumed, in that case DVRI is set equal to DVRJ.

Ambohibary

Ambohibary is markedly different from the West African sites, it is much colder (Figure 2.2). Limited good quality calibration data are available and the ORYZA2000 model was never before extensively calibrated for this site. Therefore we are much more uncertain for this site. For sensitivity analysis, two sets of simulations were carried out (Ambohibary (1) and Ambohibary (2)). For sowing to emergence in set 1 we assumed a fixed duration from sowing to emergence (8 days) and a fixed duration from emergence to transplanting (28 days), thus a constant 36 days duration from sowing to transplanting. In set 2, duration from sowing to transplanting was varied between 15 and 70 days depending on the planting date, longest duration in winter and shortest in summer. For set 2, sinusoid functions were fitted to RGT data such that longest duration would occur on the shortest day of the year (Figure 2.3), which corresponds with the coldest part of the year in mid-July.

Next phenology from emergence to panicle initiation, flowering and maturity was calibrated in two ways. In set 1, development rates were calibrated following the same approach as described above for Kano and Niono. Phenological parameters were calibrated using the local common sowing date, assuming TBD = 14 °C, TOD =31 °C and assuming development rate staying at its highest level for temperatures above TOD. In set 2, cardinal temperatures and development rates were calibrated using the pheno_opt_rice calibration program (van Oort et al., 2011) using data of 4 sowing dates from the Ambohibary rice-garden trials (RGT) for the local popular variety Rapida. The 5th RGT sowing date which occurred in late autumn was excluded because it was considered too uncertain to be used for calibration.

Table 2.2 *Current common cropping calendars for the locally popular variety.*

Country	Location	Rice season 1 [1] Start [2]	Rice season 1 [1] End [3]	Rice season 1 [1] Total days [3]	Rice season 2 [1] Start [2]	Rice season 2 [1] End [3]	Rice season 2 [1] Total days [3]	Local popular variety
Senegal	Fanaye	01-Mar	26-Jun	117	29-Jul	13-Nov	107	Sahel 108
Mali	Niono	09-Feb	15-Jun	126	29-Jun	14-Nov	138	Andy 11
Nigeria	Kano	11-Mar	22-Jun	103	29-Jun	25-Oct	118	FARO44
Madagascar	Ambohibary	17-Oct	13-Mar	147				Rapida

[1] Rice seasons are presented in order of planting dates, i.e. first season 1 then season 2. In the Madagascar site there is only 1 rice season (in the summer period). In the three West African sites, season 1 is the hot dry season, season 2 is the main (wet) season and no rice is grown in the cold dry season.

[2] Simulations start on day 10, 20, ..., 360. If e.g. the local common start date is 14 Jan, then this is rounded to the closest 10-fold, thus set to 10 jan.

[3] End dates and total days in the table are 19-year average simulated values, simulated such that the error was minimised when comparing with observed local common end dates (not shown; compiled in the GYGA project). Where two season are shown, the same variety was used in both seasons and average error over the seasons was minimised.

Table 2.3 *Phenological parameters.*

	Site				
	Senegal Fanaye	Nigeria Kano	Mali Niono	Madagascar Ambohibary (1)	Madagascar Ambohibary (2)
Sowing to emergence	3-8 days, longer in colder part of the year(van Oort et al., 2016)	4 days	4 days	8 days	7-13 days, longer in colder part of the year (Figure 2.3)
Crop establishment	Direct-seeding	Transplanting	Transplanting	Transplanting	Transplanting
Seedbed duration SBDUR (emergence to transplanting)		28 days	28 days	28 days	7-55 days, later transplanting in colder part of the year (Figure 2.3)
Transplanting shock SHCKD on development		0.4	0.4	0.4	1.0
TBD (°C)	15	14	14	14	10
TOD (°C)	34	31	31	31	18
TMD (°C)	DVR remains optimum above TOD	DVR remains optimum above TOD	DVR remains optimum above TOD	DVR remains optimum above TOD	42
DVRJ (d^{-1})	0.012849	0.015055	0.021322	0.029514	0.008889
DVRI (d^{-1})	0.012849	0.015055	0.021322	0.029514	0.015625
DVRP (d^{-1})	0.020588	0.011717	0.016328	0.024116	0.016667
DVRR (d^{-1})	0.047619	0.038646	0.041427	0.091843	0.043478

TBD = Base Temperature for development; TOD = optimum temperate for development; no maximum temperature for development because development rate is assumed to remain at its maximum above TOD; DVRJ = development rate for the basic vegetative phase (BVP), not photoperiod sensitive; DVRJ = development rate for the photoperiod phase (PSP) which ends at panicle initiation, in this period we assumed no photoperiod sensitivity in that case DVRI equals DVRJ; DVRP = development rate for the panicle formation phase (PFP), from panicle initiation to 50% flowering; DVRR = development rate for the grain filling phase (GFP) from (50%) flowering to physiological maturity. Development rates used here are normalised resulting in units d-1 instead of the normal oCd-1, see van Oort et al. (2011).

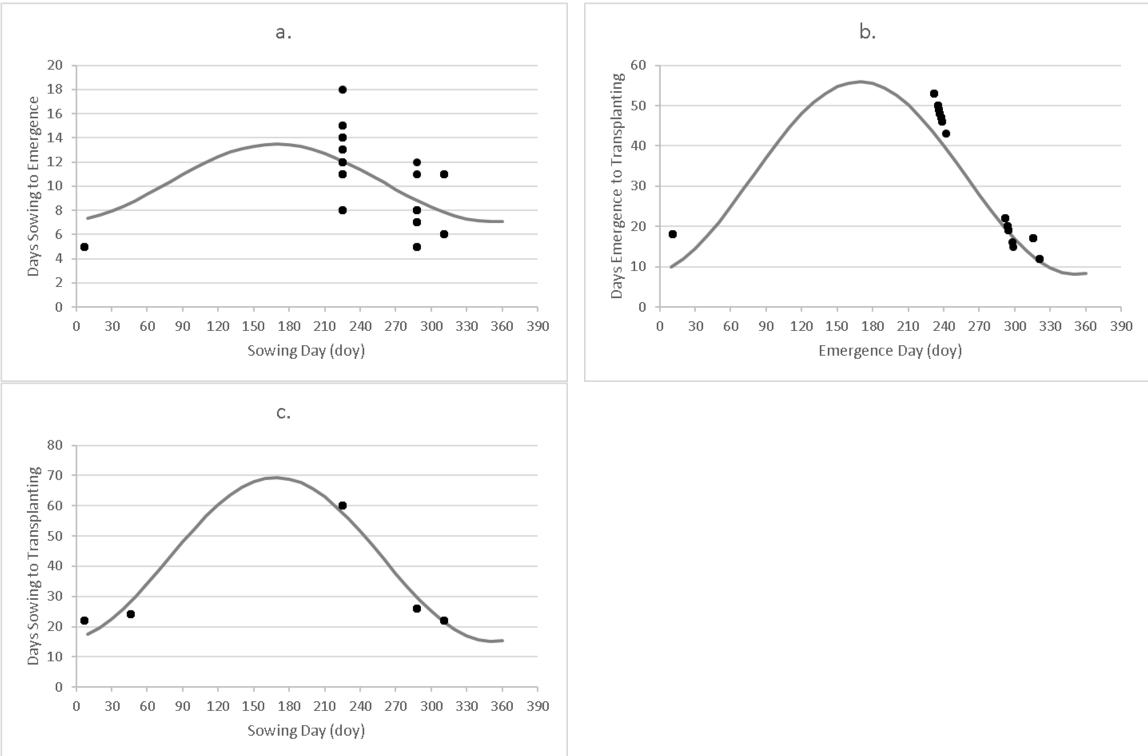

Figure 2.3 *Ambohibary: Duration sowing to emergence (a), emergence to transplanting (b) and sowing to transplanting . Dots represent observations from the Rice Garden Trials with 5 sowing dates and 80 varieties. All varieties were sown and transplanted on the same date (c). Varieties differed in number of days from sowing to emergence (a) and as a result also the number of days from emergence*

to transplanting also varies (b). The solid lines show sinusoid functions fitted through these data and were used in the second set of simulations for this site.

2.2.3 Variety adaptation options

After calibration of the DVR parameters for the baseline locally popular variety in each site, 4 "in-silico" varieties were generated by multiplying DVR parameters of the baseline locally popular variety with 0.7, 0.85, 1.15 and 1.30 to obtain longer and shorter duration varieties for each site. The variety with DVR multiplied with 0.7 will have much slower development and therefore a much longer duration compared with the baseline. Of course duration from sowing to maturity will also depend on temperature and therefore on sowing date, as is simulated by the model and as will be seen in the results.

To assess if these "in-silico" varieties are within genetically realistic bounds, we compared three simulated "in-silico" varieties (shortest, baseline and longest duration) with 80 varieties observed in rice garden trials (RGT) for 5 sowing dates in Fanaye and Ambohibary.

2.3 Climate scenarios

For the current situation daily weather data were used of 19 years (1991-2009) from the AgMERRA, weather dataset (Ruane et al., 2015). Data centred around the year 2000 were used and not a more recent year because (1) the AgMERRA weather set only covers the period 1980-2010 and because (2) the year 2000 is the baseline in the RCP scenarios used (Zwart, 2016). Changes in temperature are given relative to the baseline year 2000. In 2000 atmospheric CO_2 concentration was 368.9 ppm, in 2050 according to the RCP8.5 scenario it will be 540.5 ppm.

One future climate scenario was considered: RCP8.5 around the year 2050. Simulations were made using the same 19 years as in the current climate, but with elevated CO_2 and temperatures from Zwart (2016). Climate change scenarios differ spatially, Table 2.4 shows the future climate change scenario analysed. Notably, temperature rise is least in Fanaye and largest in the two more inland sites Niono and Kano.

Table 2.4 *Climate change scenario.*

Country	Location	ΔTmin (°C)	ΔTmax (°C)	CO2 (ppm)
Madagascar	Ambohibary	2.6	3.5	540.5
Mali	Niono	3.9	3.6	540.5
Nigeria	Kano	4.0	2.3	540.5
Senegal	Fanaye	2.2	1.8	540.5

2.4 Cropping calendar options

First potential yields and duration from sowing to maturity were simulated for 36 sowing dates (10 days interval) for 5 varieties (§2.2.2) for 19 years for each climate scenario (§2.3). For each sowing date and variety the 19-years average, minimum and maximum were calculated, for the duration from sowing to maturity and for the yield. From these 36 x 5 = 180 individual growing seasons, five possible cropping calendar options were constructed (van Oort et al., 2016):

1. Single Rice
2. Rice – other
3. Rice - rice
4. Rice - rice - other
5. Rice - rice - rice

Within each cropping calendar option there can be hundreds or even thousands of possible combinations of different sets of sowing dates and varieties. In the double and triple cropping systems, a minimum of 15 days was assumed between harvesting one crop and seeding or transplanting the next crop. If for example rice crop 2 is seeded in the nursery 10 days before harvesting rice crop 1, and if rice crop 2 stays in the nursery for 28 days, then it is transplanted 28-10 = 18 days after harvesting. Thus a second transplanted crops can be sown before harvest of the first crop, as long as transplanting is >15 days after harvest. A second direct-seeded crop must be sown at least 15 days after harvest of the first crop.

In reality it is possible that farmers grow different varieties in season 1, season 2 and season 3. This option was not simulated here, because it would have resulted in more than 100,000 simulations per site, too much detail too handle. Thus, in the options 3, 4 and 5 a single variety is chosen from a list of 5 possible varieties (§2.2), and this variety was grown in all two or three simulated seasons.

Options 2 and 4 allow for blocking a period for growing another crop. Different periods were blocked on a monthly time step for periods of at least 60 days (2 months). Thus it is for example possible to block the period from mid-December to mid-April for vegetable cropping, and search for various options for rice in the remaining "available" part of the year from mid-April (+15 days) to mid-December (– 15 days).

Altogether, the cropping calendar construction algorithms (van Oort et al., 2016) generate per site several thousands of configurations of climate scenario x cropping calendar option x variety x sowing date(s). For each site a so-called CCC Excel file (see Appendix) was generated. Such a file contains:

- A sheet called "AllOptions" with per site all possible configurations of climate scenario x cropping calendar option x variety x sowing date(s);
- An English and French user interface for querying these configurations;
- Figures visualising the options; figures are automatically updated based on input choices in the user interface;
- Specifically for the current study, the results for 10 adaptation options (next section).

In the user interface (Fig. A.2 in the appendix) one can select:

1. Climate scenario
2. Criteria for crop rotation
    2.1. Crop rotation option (single rice, ..., rice-rice-other)
    2.2. Variety(s) (one, or compare all 5)
3. Rice sowing dates (optimise or user defined)
4. Blocked period (e.g. mid-December to mid-April)
5. Minimum days between crops (in the current study fixed at 15 days)
6. What to optimise: yield or yield per unit time (see section 3.6 of this report and see (van Oort et al., 2016) for a rationale)

Tables and Figures reported in the current study were all extracted through querying the user interface.

2.5 Adaptation options

2.5.1 Options in the current climate

The following options were analysed for the current climate (i.e. around the year 2000):

1.1. Current cropping calendar and variety
1.2. Maximise yield by changing variety
1.3. Maximise yield by changing sowing dates
1.4. Maximise yield by changing sowing dates AND variety

2.5.2 Climate change adaptation options

Climate change impact and adaptation options were analysed by comparing yields in the current climate with yields in the future climate. The following adaptation options were considered:

2.1. No adaptation, business as usual
2.2. Maximise yield by changing variety
2.3. Maximise yield by changing sowing dates
2.4. Maximise yield by changing sowing dates AND variety
2.5. Maximise yield by changing sowing dates AND cropping intensity
2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety

The rationale for considering additional options 5 and 6 is that in cold sites such as Ambohibary, a future opportunity could be to increase cropping intensity from 1 to 2 rice crops per year. In hot sites opportunities may arise for increasing cropping intensity from 2 to 3 rice crops per year. In extremely hot sites, two crops might turn out to be no longer viable, in which case it may be better to go from 2 rice crops to 1 rice crop per year.

2.5.3 Effectiveness of adaptation options

The relative yield change *RYC(s,o)* was calculated as:

$$RYC(s,o) = \frac{\sum_c Y_p(s,o)}{\sum_c Y_p(s,1.1)} \quad (1)$$

Where $\sum_c Y_p(s,o)$ is the sum over potential yield over c = 1,2,3 rice crops in a year in a specific site s = 1,...,4 for adaptation option o (o = 1.1, ..., 2.6). In which the benchmark is option o = 1.1, i.e. the Current cropping calendar and common variety.

3 Results

Sections 3.1 to 3.4 describe per site the potential impact of climate change, with and without adaptation. Section 3.5 provides a comparison between the sites, section 3.6 presents trade-offs between the different adaptation options.

3.1 Senegal, Fanaye

3.1.1 Validation

Figure 3.1a shows the validation for the duration from sowing to maturity for the local popular variety Sahel 108. The model accurately simulates the days from sowing to maturity throughout the year. We therefore trust the model can also accurately simulate yields, given previous model testing for yields of a similar variety (IR64) in the same study site (van Oort et al., 2015a).

Figure 3.1b shows in lines simulated duration (shortest, baseline and longest out of 5 simulated varieties) and in square dots for 5 sowing dates the observed duration (shortest, baseline and longest duration, out of 80 varieties tested at 5 sowing dates in Rice Garden Trials). Figure 3.1b shows that varieties exist with duration even shorter and even longer than simulated. This implies that the 5 simulated "in-silico" varieties are within genetically realistic bounds.

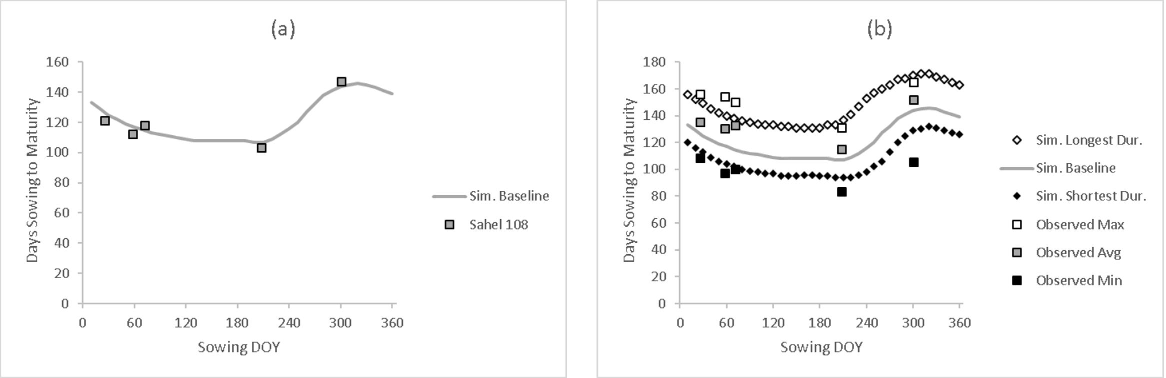

Figure 3.1 *Validation for Fanaye, Senegal. Continuous lines show simulated averages, which are validated with observation data from Rice Garden Trials at 5 sowing dates. (a) validation for the local popular variety Sahel 108; (b) comparison of simulated and observed variation between varieties. For observed data 80 varieties are compared. For each sowing date the shortest, average and longest duration are shown.*

3.1.2 Adaptation options

Figure 3.2 shows potential yields in the current and future scenario. In the current climate, planting in September-November shows risks of almost complete crop failure due to cold. Similar high yields of ~9t/ha are predicted when planting in the period of January to June. The yield pattern changes little in the RCP8.5 scenario, the main change is that cold stress decreases.

Table 3.1 shows simulated 19-year average crop yields for Fanaye. For current cropping calendar and popular variety, long term average potential yield is 9.1 + 7.4 = 16.5 t/ha (option 1.1). Possibilities exist for increasing yields through changing variety (option 1.2, yield +8%), sowing dates (option 1.3, yield +7%) or both (option 1.4: yield +19%).

Simulations suggest a near zero climate change impact (Table 3.1, option 2.1, -5%). Switching to a longer duration variety could increase yields by +13% (Table 3.1, option 2.2). Future yields could be increased by +17% when planting variety 'Sahel 108' 60 days earlier than now (option 2.3). Future yields could be increased by +29% when planting -95 and -70 days earlier than now (option 2.4) in combination with switching to a longer duration variety. Simulations showed that triple cropping with the current variety would not be possible in the future climate. Triple cropping would become possible if a shorter duration variety would be adopted (option 2.6), with potential yields of 9.7 + 7.9 + 7.6 = 25.3 t/ha, 53% higher than in the current situation and 19% higher than the highest attainable double crop yield in 2050. Figure 3.3 shows graphically the cropping calendars in the current situation (option 1.1) and for climate change adaptation option 2.4.

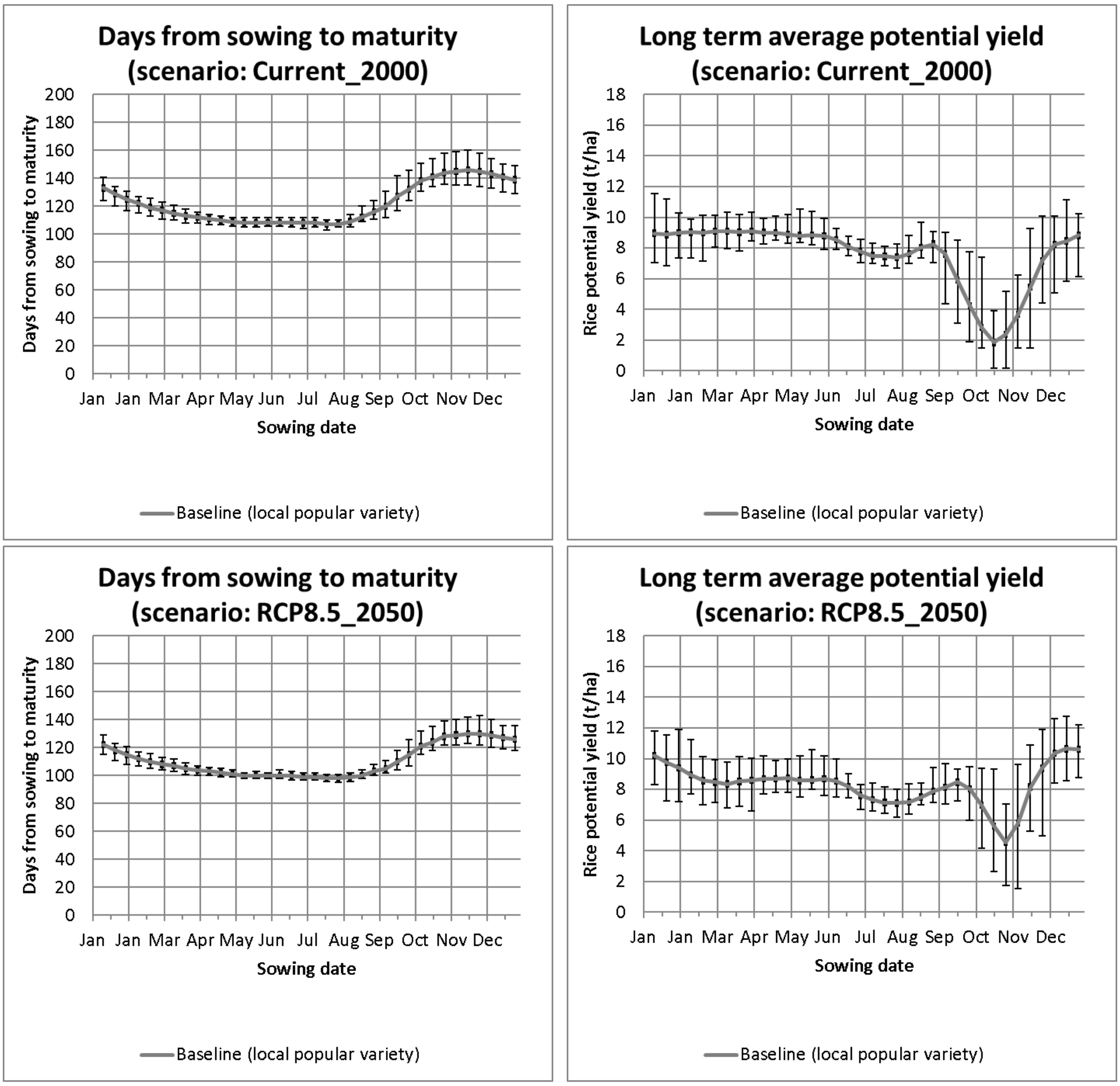

Figure 3.2 *Crop duration and yield potential in Senegal, Fanaye in the current climate (around year 2000) and future climate (around 2050, scenario RCP8.5).*

Table 3.1 *Adaptation Options for Fanaye.*

Site	Climate Scenario	Adaptation Option	S1	S2	S3	Total	Relative to Current	Change
Fanaye	Current_2000	1.1. Current cropping calendar and variety	9.1	7.4		16.5	1.00	
Fanaye	Current_2000	1.2. Maximise yield by changing variety	9.8	8.1		17.9	1.08	Longer duration variety
Fanaye	Current_2000	1.3. Maximise yield by changing sowing dates	8.8	8.8		17.6	1.07	Planting dates changed from DOY (day of year) 60 and 180 to 350 and 160, i.e. -85 and -20 days earlier
Fanaye	Current_2000	1.4. Maximise yield by changing sowing dates AND variety	10.4	9.2		19.6	1.19	Variety with crop duration longer than baseline + Planting dates changed from DOY 60 and 210 to 40 and 210, i.e. -20 days earlier for the dry season crop
Fanaye	RCP8.5_2050	2.1. No adaptation, business as usual	8.5	7.1		15.6	0.95	
Fanaye	RCP8.5_2050	2.2. Maximise yield by changing variety	10.0	8.7		18.7	1.13	Variety with crop duration Much longer than baseline
Fanaye	RCP8.5_2050	2.3. Maximise yield by changing sowing dates	8.7	10.6		19.3	1.17	Planting dates changed from DOY 60 and 210 to 350 and 150, sowing dates -65 and -60 days earlier
Fanaye	RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	9.7	11.6		21.3	1.29	Variety with crop duration longer than baseline + Planting dates changed from DOY 60 and 210 to 330 and 140, planting -95 and -70 days earlier
Fanaye	RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity						Triple rice will not be possible with baseline variety
Fanaye	RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	9.7	7.9	7.6	25.3	1.53	Triple rice with variety with crop duration shorter than baseline

S1 = rice season 1, ..., S3 = rice season 3. Seasons are in order of planting date, not in order of importance. See table 3.8 for planting dates and harvest dates. RYC is the relative yield change compared with option 1.1 (eq 1)

Table 3.2 *Detailed cropping calendars for Fanaye.*

		0	Rice season 1						Rice season 2						Rice season 3						Totals			
Climate Scenario	**Adaptation Option**	**Rice Variety**	**Sowing DOY**	**Harvesting DOY**	**Days Sowing 2 Harvesting**	**Yp (t/ha)**	**Sowing MONTH**	**Harvesting MONTH**	**Sowing DOY**	**Harvesting DOY**	**Days Sowing 2 Harvesting**	**Yp (t/ha)**	**Sowing MONTH**	**Harvesting MONTH**	**Sowing DOY**	**Harvesting DOY**	**Days Sowing 2 Harvesting**	**Yp (t/ha)**	**Sowing MONTH**	**Harvesting MONTH**	**Total Yp (t/ha)**	**Total Main Field Days**	**Free days**	**Yield / Days (kg/ha/day)**
Current_2000	1.1. Current cropping calendar and variety	Baseline	60	177	117	9.1	Mar	Jun	210	317	107	7.4	Jul	Nov							16.5	224	141	74
Current_2000	1.2. Maximise yield by changing variety	Longer than baseline	60	187	127	9.8	Mar	Jul	210	328	118	8.1	Jul	Nov							17.9	245	120	73
Current_2000	1.3. Maximise yield by changing sowing dates	Baseline	150	258	108	8.8	May	Sep	360	134	139	8.8	Dec	May							17.6	247	118	71
Current_2000	1.4. Maximise yield by changing sowing dates AND variety	Much longer than baseline	40	185	145	10.4	Feb	Jul	210	347	137	9.2	Jul	Dec							19.6	282	83	70
RCP8.5_2050	2.1. No adaptation, business as usual	Baseline	60	168	108	8.5	Mar	Jun	210	308	98	7.1	Jul	Nov							15.6	206	159	76
RCP8.5_2050	2.2. Maximise yield by changing variety	Much longer than baseline	60	190	130	10	Mar	Jul	210	332	122	8.7	Jul	Nov							18.7	252	113	74
RCP8.5_2050	2.3. Maximise yield by changing sowing dates	Baseline	150	250	100	8.7	May	Sep	350	112	127	10.6	Dec	Apr							19.3	227	138	85
RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	Much longer than baseline	140	261	121	9.7	May	Sep	330	118	153	11.6	Nov	Apr							21.3	274	91	78
RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity																							
RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	Shorter than baseline	20	131	111	9.7	Jan	May	150	243	93	7.9	May	Aug	260	360	100	7.6	Sep	Dec	25.3	304	61	83

'* Tables 3.5 and 3.6 show simulated potential yields Yp and simulated duration from sowing to harvesting averaged over 19 years. Potential yield is expressed in tonne / hectare, and is defined as the rough (unmilled) rice yield at 14% moisture content. Potential means assuming no nutrient and water stress, free from weeds pests and diseases and free from soil toxicities. In reality actual yields Ya will often be lower than potential, this is called the yield gap. The direction of the response to temperature and radiation is similar for Yp and Ya. The results in this table are therefore best used for comparing between options in a relative sense, e.g. how much does yield relatively change from one option to the other.

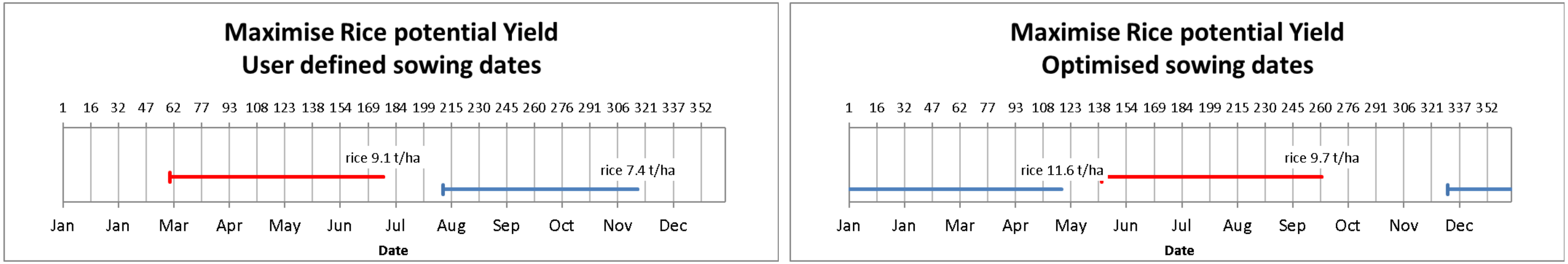

Figure 3.3 *Senegal, Fanaye: Current cropping pattern (option 1.1) and selected cropping pattern for the future climate (around 2050, scenario RCP8.5, option 2.4). In the right pane, the start of the red crop in mid-May is hidden behind the 11.6 t/ha label of the blue crop.*

3.2 Mali, Niono

A validation such as presented for Fanaye was not possible for Niono due to lack of data. However given the similarities between the environments (Figure 2.2), the high accuracy for phenology in Fanaye (§3.1.1) and previous calibrations for crop yield and cropping calendars in Fanaye (van Oort et al., 2015a; van Oort et al., 2016), we are also fairly confident about the results presented here for Niono.

Figure 3.4 shows potential yields in the current and future scenario. In the current climate, planting in October-November shows risks of almost complete crop failure due to cold induced sterility. Highest yields are predicted when planting in May to August. In the RCP8.5 scenario the yield patterns is strongly changed. Planting in January will lead to substantial yield reduction, while September-November becomes a period with high yield, due to a slightly longer season than the rest of the year, less heat than in the rest of the year and (compared with the current climate) reduced cold risk.

Table 3.3 shows simulated 19-year average crop yields for Niono. For the current cropping calendar and popular variety, long term average potential yield is 6.9 + 9.4 = 16.3 t/ha. According to the simulations, large improvements are possible in the current climate. Yield could be increased by +26% with a longer duration variety, +22% by changing sowing dates and +36% by changing both variety (much longer duration) and sowing date.

According to the simulations, without adaptation climate change would reduce yields from 6.9 + 9.4 = 16.3 t/ha to 2.4 + 7.8 = 10.3t/ha, a -37% yield reduction (Table 3.3, option 2.1). The largest yield reduction, from 6.9 to 2.4 t/ha occurs for planting day 40 (9 February). This yield reduction is caused by a combination of shortening of the growing period and reduced photosynthesis at extremely high temperatures (see (van Oort and Zwart, 2018) on causes of yield changes). Varieties with a longer duration alleviate the negative impact of shortening of the season, but the crop continues growing in the hot dry season. Adaptation through change of variety, leads to a -12% yield reduction (Table 3.3, option 2.2). A more effective adaptation option is through a big shift in sowing date, from day 40 (9-Feb) to 150 (29-May) and from day 180 (29-Jun) to 260 (16 Sept), i.e. +110 and +80 days later than now (Table 3.4, option 2.3). With this sowing date adaptation, yields would slightly increase by +8% (Table 3.3, option 2.3), a big change compared with the -37% yield reduction without adaptation. Changing both sowing date and variety gives the most positive impact, +29% (Table 3.3, option 2.4) compared with the current situation.

Two possible changes in cropping intensity are possible: from 2 to 1 and from 2 to 3 rice crops per year. Going from 2 to 1 rice crops per year was not considered because results showed that with a rice double crop, still high yields of >8.5t/ha are possible (Table 3.3, options 2.3 and 2.4). Simulations showed that going from 2 to 3 inevitably exposes one of the three crops to the (too) hot dry season, with a potential yield of only 2.9 t/ha. Total potential yield in triple cropping is 20.6 t/ha (options 2.5 and 2.6 with same result). This is less than what is attainable with double cropping (option 2.4, 21.0 t/ha). Therefore in Niono, a change in cropping intensity is not recommendable.

Figure 3.5 shows graphically the cropping calendars in the current situation (option 1.1) and for climate change adaptation option 2.4.

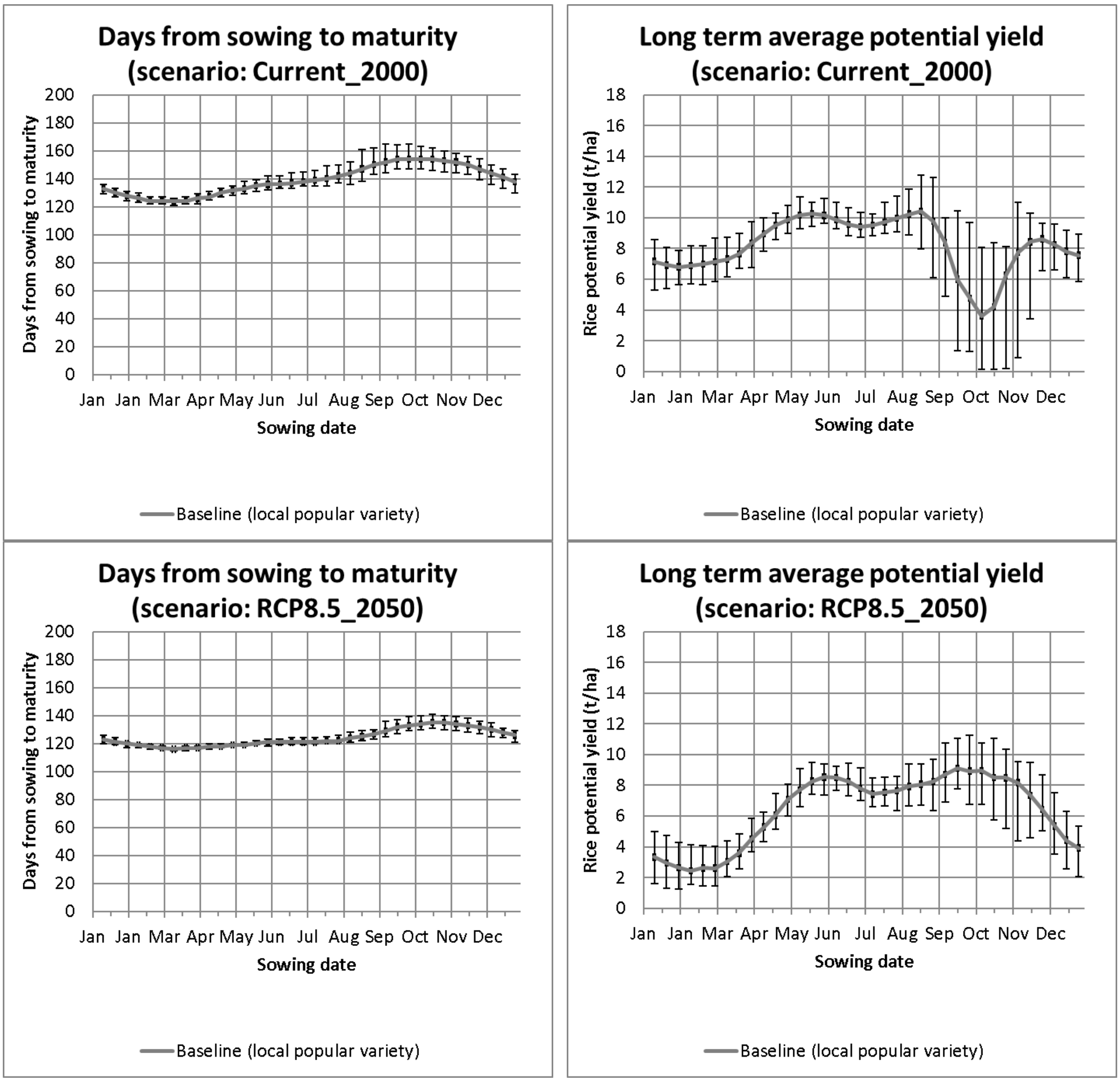

Figure 3.4 *Crop duration and yield potential in Mali, Nino in the current climate (around year 2000) and future climate (around 2050, scenario RCP8.5).*

Table 3.3 *Adaptation Options for Niono.*

Site	Climate Scenario	Adaptation Option	S1	S2	S3	Total	Relative to Current	Change
Niono	Current_2000	1.1. Current cropping calendar and variety	6.9	9.4		16.3	1.00	
Niono	Current_2000	1.2. Maximise yield by changing variety	9.5	11.1		20.6	1.26	Variety with crop duration longer than baseline
Niono	Current_2000	1.3. Maximise yield by changing sowing dates	9.5	10.4		19.9	1.22	Planting dates changed from DOY (day of year) 40 and 180 to 110 and 230, i.e. +70 and +50 days
Niono	Current_2000	1.4. Maximise yield by changing sowing dates AND variety	10.6	11.4		22.1	1.36	Variety with crop duration Much longer than baseline + Planting dates changed from DOY 40 and 180 to 70 and 210
Niono	RCP8.5_2050	2.1. No adaptation, business as usual	2.4	7.8		10.3	0.63	
Niono	RCP8.5_2050	2.2. Maximise yield by changing variety	5.2	9.3		14.4	0.88	Variety with crop duration Much longer than baseline
Niono	RCP8.5_2050	2.3. Maximise yield by changing sowing dates	8.5	9.1		17.6	1.08	Planting dates changed from DOY 40 and 180 to 150 and 260, i.e. +110 and +80 days later
Niono	RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	10.3	10.8		21.0	1.29	Variety with crop duration Much longer than baseline + Planting dates changed from DOY 40 and 180 to 120 and 250, i.e. +80 and +70 days
Niono	RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity	2.9	8.5	9.1	20.6	1.26	Change to triple rice. Crop planted on day 20 gives really low potential yield of 2.9 t/ha. Scenario of going from 2 to 1 rice crop per year was not considered, because double cropping can still give good yields
Niono	RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	2.9	8.5	9.1	20.6	1.26	Baseline variety is also the best for triple cropping

S1 = rice season 1, ..., S3 = rice season 3. Seasons are in order of planting date, not in order of importance. See table 3.4 for planting dates and harvest dates. RYC is the relative yield change compared with option 1.1 (eq 1)

Table 3.4 *Detailed cropping calendars for Niono.*

		0	Rice season 1						Rice season 2						Rice season 3						Totals			
Climate Scenario	Adaptation Option	Rice Variety	Sowing DOY	Harvesting DOY	Days Sowing 2 Harvesting	Yp (t/ha)	Sowing MONTH	Harvesting MONTH	Sowing DOY	Harvesting DOY	Days Sowing 2 Harvesting	Yp (t/ha)	Sowing MONTH	Harvesting MONTH	Sowing DOY	Harvesting DOY	Days Sowing 2 Harvesting	Yp (t/ha)	Sowing MONTH	Harvesting MONTH	Total Yp (t/ha)	Total Main Field Days	Free days	Yield / Days (kg/ha/day)
Current_2000	1.1. Current cropping calendar and variety	Baseline	40	166	126	6.9	Feb	Jun	180	318	138	9.4	Jun	Nov							16.3	208	157	62
Current_2000	1.2. Maximise yield by changing variety	Much longer than baseline	40	187	147	9.5	Feb	Jul	180	343	163	11.1	Jun	Dec							20.6	254	111	66
Current_2000	1.3. Maximise yield by changing sowing dates	Baseline	110	240	130	9.5	Apr	Aug	230	12	147	10.4	Aug	Jan							19.9	221	144	72
Current_2000	1.4. Maximise yield by changing sowing dates AND variety	Much longer than baseline	70	216	146	10.6	Mar	Aug	210	17	172	11.4	Jul	Jan							22.1	262	103	69
RCP8.5_2050	2.1. No adaptation, business as usual	Baseline	40	159	119	2.4	Feb	Jun	180	301	121	7.8	Jun	Oct							10.3	184	181	43
RCP8.5_2050	2.2. Maximise yield by changing variety	Much longer than baseline	40	178	138	5.2	Feb	Jun	180	322	142	9.3	Jun	Nov							14.4	224	141	52
RCP8.5_2050	2.3. Maximise yield by changing sowing dates	Baseline	150	271	121	8.5	May	Sep	260	27	132	9.1	Sep	Jan							17.6	197	168	70
RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	Much longer than baseline	120	259	139	10.3	Apr	Sep	250	38	153	10.8	Sep	Feb							21	236	129	72
RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity	Baseline	20	141	121	2.9	Jan	May	150	271	121	8.5	May	Sep	260	27	132	9.1	Sep	Jan	20.6	290	75	55
RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	Baseline	20	141	121	2.9	Jan	May	150	271	121	8.5	May	Sep	260	27	132	9.1	Sep	Jan	20.6	290	75	55

'* Tables 3.3 and 3.4 show simulated potential yields Yp and simulated duration from sowing to harvesting averaged over 19 years. Potential yield is expressed in tonne / hectare, and is defined as the rough (unmilled) rice yield at 14% moisture content. Potential means assuming no nutrient and water stress, free from weeds pests and diseases and free from soil toxicities. In reality actual yields Ya will often be lower than potential, this is called the yield gap. The direction of the response to temperature and radiation is similar for Yp and Ya. The results in this table are therefore best used for comparing between options in a relative sense, e.g. how much does yield relatively change from one option to the other.

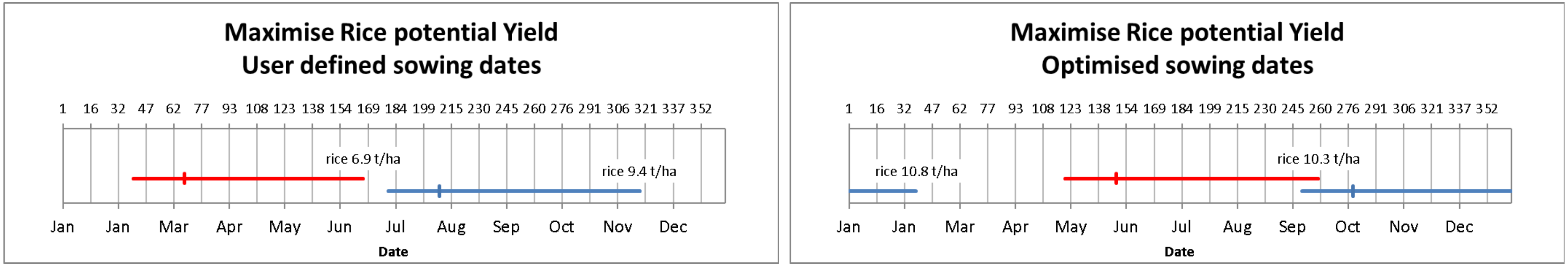

Figure 3.5 *Mali: Niono: Current cropping pattern (option 1.1) and selected cropping pattern for the future climate (around 2050, scenario RCP8.5, option 2.4).*

3.3 Nigeria, Kano

A validation such as presented for Fanaye was not possible for Kano due to lack of data. However given the similarities between the environments (Figure 2.2), the high accuracy for phenology in Fanaye (§3.1.1) and previous calibrations for crop yield and cropping calendars in Fanaye (van Oort et al., 2015a; van Oort et al., 2016), we are also fairly confident about the results presented here for Kano.

Figure 3.6 shows potential yields in the current and future scenario. In the current climate, planting in September-November shows risks of almost complete crop failure due to cold. Highest yields are predicted when planting in June to July. In the RCP8.5 scenario the yield pattern is similar with overall lower yield levels except for the September-November period in which cold risk decreases leading to higher yield levels.

Table 3.5 shows simulated 19-year average crop yields for Kano. For current cropping calendar and popular variety, long term average potential yield is 4.6+8.3=13.0 t/ha. Especially for the planting day 70 (11 March), the combination of high temperatures and very short duration (103 days from sowing to maturity) leads to a low potential yield level of 4.6 t/ha. According to the simulations, large improvements are possible in the current climate. Changing variety at the same sowing date increases total yield to 8.7+10.2=18.9 t/ha, i.e. +45% (Table 3.5, option 1.2). Changing sowing dates increases total yield to 8.4+7.8=16.2 t/ha, i.e. +25% (Table 3.5, option 1.3). Changing both sowing dates and variety increases total yield to 10.5+9.9 = 20.4 t/ha, i.e. +57% (Table 3.5, option 1.4).

According to the simulations, without adaptation yields would decrease from 4.6 + 8.3 = 13.0 to 2.9 + 6.5 = 9.4 t/ha, a -28% yield reduction (Table 3.5, option 2.1). The largest yield reduction, from 4.6 to 2.9 occurs for planting day 70 (11 March) and is caused in part by the growing period becoming very short, from 103 days in 2000 to 95 days in 2050. Changing to a variety with a 30% lower development rate at the same sowing dates (option 2.2) would turn the -28% yield reduction into a +18% yield increase. Changing sowing dates is less effective (option 2.3, +11%) than changing variety. Changing both sowing date and variety (option 2.4), with both sowing dates 70 days later than now, could increase yields by +49%.

Simulations show it is possible to go from 2 to 3 rice varieties in Kano in the future climate. A triple crop with the current variety increases yields by +54% compared with the current situation. This is hardly any better than what can be achieved with a double crop (+49%) thus not an attractive option. A triple crop with a variety with a 30% lower development rate is an attractive option, in that case yields would increase by +121% (!) compared with the current situation (in 2000) and by +42% compared with the highest attainable double crop. As can be seen in Figure 3.7 this option offers very little flexibility, thus it will only be feasible with tight logistics. That is timely availability of labour, seeds and machinery.

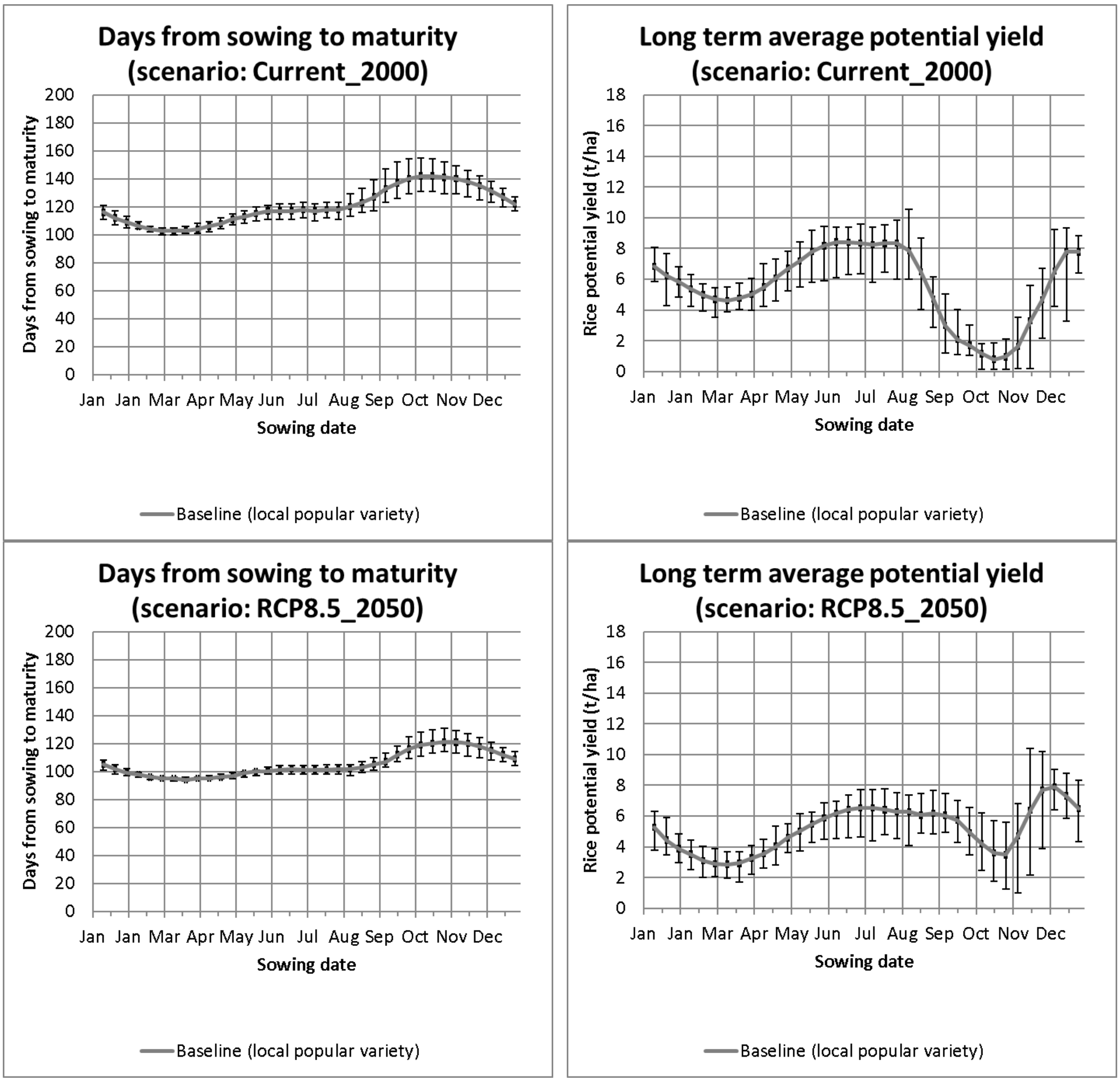

Figure 3.6 *Crop duration and yield potential in Nigeria, Kano in the current climate (around year 2000) and future climate (around 2050, scenario RCP8.5).*

Table 3.5 *Adaptation Options for Kano.*

Site	Climate Scenario	Adaptation Option	S1	S2	S3	Total	Relative to Current	Change
Kano	Current_2000	1.1. Current cropping calendar and variety	4.6	8.3		13.0	1.00	
Kano	Current_2000	1.2. Maximise yield by changing variety	8.7	10.2		18.9	1.45	Variety with crop duration longer than baseline
Kano	Current_2000	1.3. Maximise yield by changing sowing dates	8.4	7.8		16.2	1.25	Planting dates changed from DOY (day of year) 70 and 180 to 350 and 160, i.e. -85 and -20 days earlier
Kano	Current_2000	1.4. Maximise yield by changing sowing dates AND variety	10.5	9.9		20.4	1.57	Variety with crop duration longer than baseline + Planting dates changed from DOY 70 and 180 to 330 and 200, i.e. -105 days earlier and +20 days later
Kano	RCP8.5_2050	2.1. No adaptation, business as usual	2.9	6.5		9.4	0.72	
Kano	RCP8.5_2050	2.2. Maximise yield by changing variety	6.4	8.9		15.3	1.18	Variety with crop duration Much longer than baseline
Kano	RCP8.5_2050	2.3. Maximise yield by changing sowing dates	6.5	7.9		14.4	1.11	Planting dates changed from DOY 70 and 180 to 340 and 180, one of the two sowing dates -95 days earlier
Kano	RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	9.0	10.4		19.4	1.49	Variety with crop duration longer than baseline + Planting dates changed from DOY 70 and 180 to 140 and 250, both +70 days later
Kano	RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity	5.9	6.2	7.9	20.0	1.54	Triple rice with baseline variety
Kano	RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	8.7	9.9	8.9	27.5	2.12	Triple rice with Variety with crop duration Much longer than baseline

S1 = rice season 1, ..., S3 = rice season 3. Seasons are in order of planting date, not in order of importance. See table 3.6 for planting dates and harvest dates. RYC is the relative yield change compared with option 1.1 (eq 1)

Table 3.6 *Detailed cropping calendars for Kano.*

		0	Rice season 1						Rice season 2						Rice season 3						Totals			
Climate Scenario	**Adaptation Option**	**Rice Variety**	**Sowing DOY**	**Harvesting DOY**	**Days Sowing 2 Harvesting**	**Yp (t/ha)**	**Sowing MONTH**	**Harvesting MONTH**	**Sowing DOY**	**Harvesting DOY**	**Days Sowing 2 Harvesting**	**Yp (t/ha)**	**Sowing MONTH**	**Harvesting MONTH**	**Sowing DOY**	**Harvesting DOY**	**Days Sowing 2 Harvesting**	**Yp (t/ha)**	**Sowing MONTH**	**Harvesting MONTH**	**Total Yp (t/ha)**	**Total Main Field Days**	**Free days**	**Yield / Days (kg/ha/day)**
Current_2000	1.1. Current cropping calendar and variety	Baseline	70	173	103	4.6	Mar	Jun	180	298	118	8.3	Jun	Oct							13	165	200	59
Current_2000	1.2. Maximise yield by changing variety	Much longer than baseline	70	189	119	8.7	Mar	Jul	180	316	136	10.2	Jun	Nov							18.9	199	166	74
Current_2000	1.3. Maximise yield by changing sowing dates	Baseline	160	277	117	8.4	Jun	Oct	350	112	127	7.8	Dec	Apr							16.2	188	177	66
Current_2000	1.4. Maximise yield by changing sowing dates AND variety	Much longer than baseline	200	338	138	10.5	Jul	Dec	330	114	149	9.9	Nov	Apr							20.4	231	134	71
RCP8.5_2050	2.1. No adaptation, business as usual	Baseline	70	165	95	2.9	Mar	Jun	180	281	101	6.5	Jun	Oct							9.4	140	225	48
RCP8.5_2050	2.2. Maximise yield by changing variety	Much longer than baseline	70	179	109	6.4	Mar	Jun	180	296	116	8.9	Jun	Oct							15.3	169	196	68
RCP8.5_2050	2.3. Maximise yield by changing sowing dates	Baseline	180	281	101	6.5	Jun	Oct	340	90	115	7.9	Dec	Mar							14.4	160	205	67
RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	Much longer than baseline	140	255	115	9	May	Sep	250	14	129	10.4	Sep	Jan							19.4	188	177	80
RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity	Baseline	150	250	100	5.9	May	Sep	240	345	105	6.2	Aug	Dec	340	90	115	7.9	Dec	Mar	20	236	129	62
RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	Much longer than baseline	120	233	113	8.7	Apr	Aug	230	351	121	9.9	Aug	Dec	340	104	129	8.9	Dec	Apr	27.5	279	86	76

'* Tables 3.5 and 3.6 show simulated potential yields Yp and simulated duration from sowing to harvesting averaged over 19 years. Potential yield is expressed in tonne / hectare, and is defined as the rough (unmilled) rice yield at 14% moisture content. Potential means assuming no nutrient and water stress, free from weeds pests and diseases and free from soil toxicities. In reality actual yields Ya will often be lower than potential, this is called the yield gap. The direction of the response to temperature and radiation is similar for Yp and Ya. The results in this table are therefore best used for comparing between options in a relative sense, e.g. how much does yield relatively change from one option to the other.

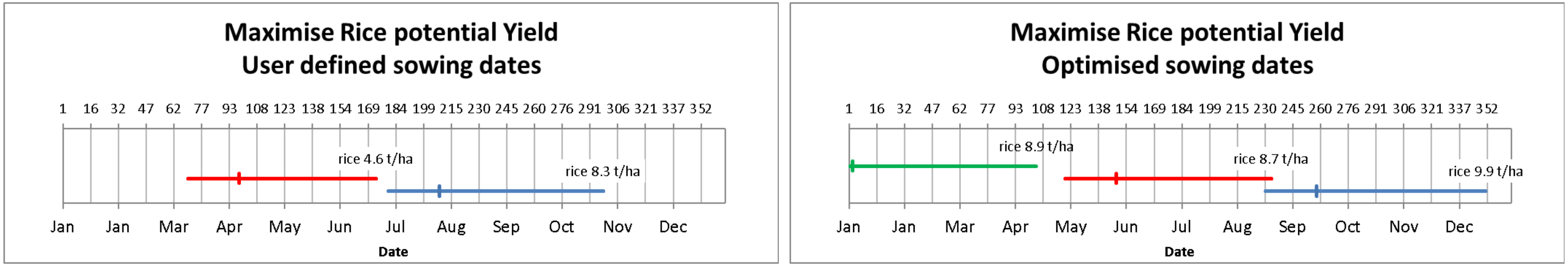

Figure 3.7 *Nigeria, Kano: Current cropping pattern (option 1.1) and selected cropping pattern for the future climate (around 2050, scenario RCP8.5, option 2.6). In the right pane, the start of the green crop in early December is hidden behind the 9.9 t/ha label of the blue crop.*

3.4 Madagascar, Ambohibary

3.4.1 Phenology remains uncertain

Two sets of simulations were conducted. In set 1, phenology was calibrated only for the local common planting date, i.e. day 290 and using a default set of phenology parameters (§2.2). In set 2, observations on the local popular variety for 4 sowing dates from Rice Garden Trials (RGT) were used for model calibration. The 5th RGT sowing date in February (day 52) with 297 days from emergence to maturity was not used because this observation was considered too uncertain to be used for model calibrations. Figure 3.8a shows set 2 calibration could accurately simulate the duration from emergence to maturity.

The two sets of simulations show systematically different simulated duration throughout the year (Figure 3.8b). Compared with set 1(solid line), set 2 (dashed line) is more accurate for the planting dates around day 10 and day 220 and less accurate for the local common planting date around day 290. Both sets predicted a too short duration for the February planting date around day 50. From day 120 to 330 set 2 predicts a longer duration from sowing to maturity, 0 to 37 days longer. For planting on day 240, set 1 predicts 160 days from sowing to maturity and set 2 predicts 197 days, i.e. 37 days longer.

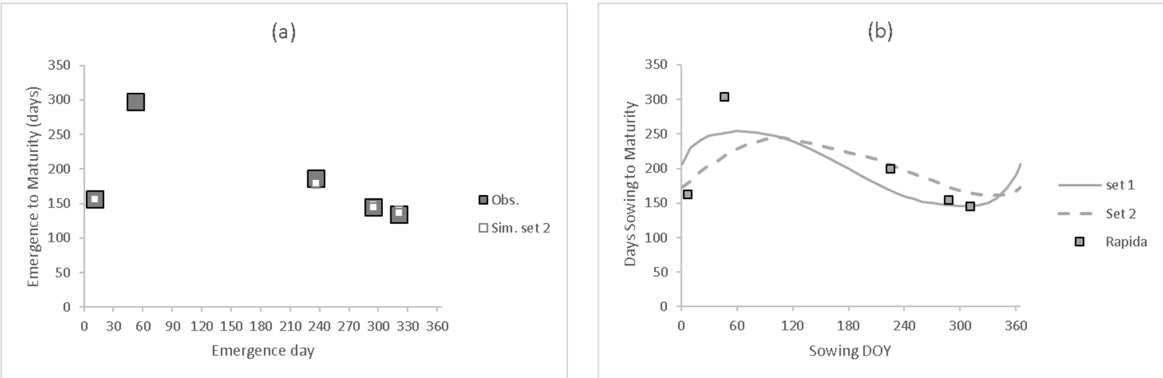

Figure 3.8 *Madagascar: Ambohibary: (a) Calibration of simulated duration from emergence to maturity and (b) simulated duration sowing to maturity (average 1991-2009) and observed for the local popular variety Rapida.*

3.4.2 Implications of uncertainty in phenological parameters

How does the above identified uncertainty about phenology affect the outcomes of analysis of climate change adaptation options? Figure 3.9 shows duration from sowing to maturity and potential yields for simulations with phenological parameter sets 1 and 2 in the current and future scenario. Simulations with two sets of phenological parameters both show for the current climate a risk of complete crop failure when planting in February to August. For the current climate simulations differ in terms of their identification of the sowing date with highest yields. With set 1, any planting date in the period from early September to late December could give a potential yield of around 13 t/ha. With set 2, there is a clear optimum for planting in September with a potential yield of around 11 t/ha and lower yields when planted outside the September month. For the current climate this implies that depending on the phenology model used one may come to completely different optimum sowing dates. This is seen in Tables 3.7 and 3.8: with set 1 the recommendation is planting +50 days later than common practice (Table 3.7, option 1.3), while with set 1 the recommendation is planting -40 days earlier than common practice (Table 3.8, option 1.3). One can conclude that the uncertainty about phenology translates into large uncertainty on adaptation options in the current climate.

For the future climate in the simulation set 1, simulated duration from sowing to maturity shortens by about -50 days, thus from ~150 days to ~100 days for planting in October (Figure 3.9). In set 2, duration shortens by about -20 days. In set 1, the yield penalty of shortening of the growing period is greater than the yield gains from CO_2 fertilisation and gains from reduced cold sterility, thus climate change has an overall negative impact (Table 3.7, option 2.1: -30%). In set 2, the yield penalty of shortening of the growing period is less than the yield gain from CO_2 fertilisation and reduced cold sterility, thus climate change has an overall positive impact (Table 3.8, option 2.1: +44%). One can conclude that the uncertainty about phenology translates into large uncertainty about climate change impact.

Possible gains from adaptation options (Tables 3.7 and 3.8) also differ greatly depending on the phenological model. Notably, the set of simulations with set 1 suggest that a promising option could be to go from the current situation of 1 crop per year to a future of 2 crops per year. With phenology parameter set 2 this would only be possible with even shorter duration varieties and would leave very little flexibility (Figure 3.10) .

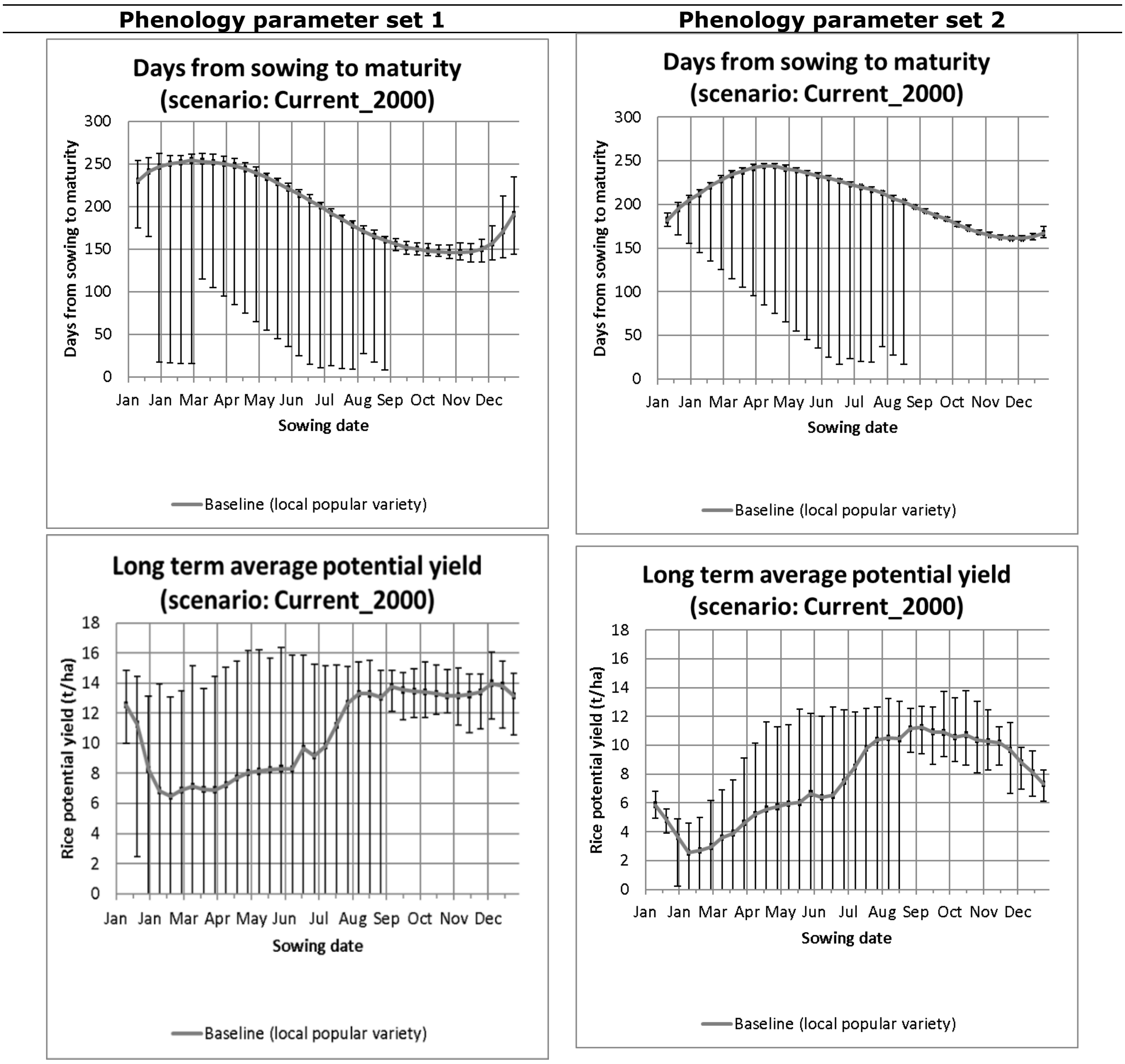

Figure 3.9 *Crop duration and yield potential in Madagascar, Ambohibary simulated with two phenological parameter sets 1 and 2, for the current climate (around year 2000) and future climate (around 2050, scenario RCP8.5).*

Phenology parameter set 1	Phenology parameter set 2

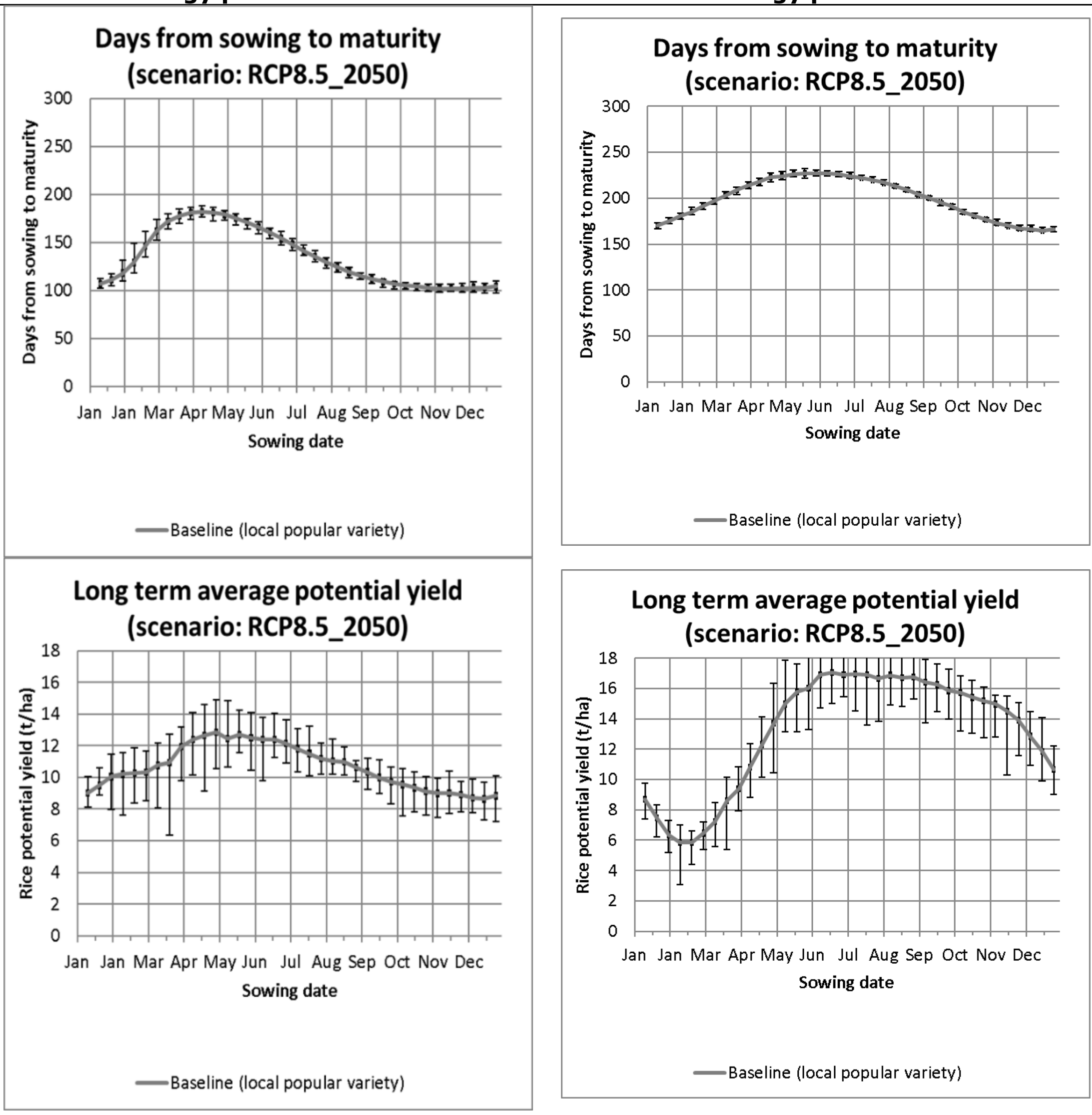

Figure 3.9 (continued) *Crop duration and yield potential in Madagascar, Ambohibary simulated with two phenological parameter sets 1 and 2, for the current climate (around year 2000) and future climate (around 2050, scenario RCP8.5).*

Table 3.7 *Adaptation Options for Ambohibary with phenology parameter set 1.*

Site	Climate Scenario	Adaptation Option	S1	S2	S3	Total	RYC	Change
Ambohibary (1)	Current_2000	1.1. Current cropping calendar and variety	13.3			13.3	1.00	
Ambohibary (1)	Current_2000	1.2. Maximise yield by changing variety	14.7			14.7	1.11	Variety with crop duration Much longer than baseline
Ambohibary (1)	Current_2000	1.3. Maximise yield by changing sowing dates	14.0			14.0	1.05	Sowing date from DOY (day of year) 290 to 340, 50 days later
Ambohibary (1)	Current_2000	1.4. Maximise yield by changing sowing dates AND variety	15.3			15.3	1.15	Variety with crop duration Much longer than baseline + sowing 30 days later
Ambohibary (1)	RCP8.5_2050	2.1. No adaptation, business as usual	9.3			9.3	0.70	
Ambohibary (1)	RCP8.5_2050	2.2. Maximise yield by changing variety	10.8			10.8	0.81	Variety with crop duration Much longer than baseline
Ambohibary (1)	RCP8.5_2050	2.3. Maximise yield by changing sowing dates	12.9			12.9	0.97	Sowing date from DOY 290 to 120, 170 days earlier = completely different season
Ambohibary (1)	RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	13.6			13.6	1.02	Variety with crop duration Much longer than baseline + Sowing date from DOY 290 to 190, 100 days earlier
Ambohibary (1)	RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity	10.1	12.7		22.8	1.71	Planting on day 30 and day 140
Ambohibary (1)	RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	12.8	13.2		26.0	1.95	Variety with crop duration Much longer than baseline + planting on day 20 and 160

S1 = rice season 1, …, S3 = rice season 3. Seasons are in order of planting date, not in order of importance. See table 3.2 for planting dates and harvest dates. RYC is the relative yield change compared with option 1.1 (eq 1)

Table 3.8 *Adaptation Options for Ambohibary with phenology parameter set 2.*

Site	Climate Scenario	Adaptation Option	S1	S2	S3	Total	RYC	Change
Ambohibary (2)	Current_2000	1.1. Current cropping calendar and variety	10.7			10.7	1.00	
Ambohibary (2)	Current_2000	1.2. Maximise yield by changing variety	10.7			10.7	1.00	
Ambohibary (2)	Current_2000	1.3. Maximise yield by changing sowing dates	11.2			11.2	1.05	Sowing date from DOY 290 to 250, 40 days earlier
Ambohibary (2)	Current_2000	1.4. Maximise yield by changing sowing dates AND variety	11.2			11.2	1.05	Sowing date from DOY 290 to 250, 40 days earlier, same variety
Ambohibary (2)	RCP8.5_2050	2.1. No adaptation, business as usual	15.4			15.4	1.44	
Ambohibary (2)	RCP8.5_2050	2.2. Maximise yield by changing variety	15.6			15.6	1.46	Variety shorter than baseline
Ambohibary (2)	RCP8.5_2050	2.3. Maximise yield by changing sowing dates	17.1			17.1	1.60	Sowing date from DOY 290 to 170, 120 days earlier = completely different season
Ambohibary (2)	RCP8.5_2050	2.4. Maximise yield by changing sowing dates AND variety	17.6			17.6	1.64	Variety with crop duration longer than baseline + Sowing date from DOY 290 to 180, 110 days earlier
Ambohibary (2)	RCP8.5_2050	2.5. Maximise yield by changing sowing dates AND cropping intensity						not possible
Ambohibary (2)	RCP8.5_2050	2.6. Maximise yield by changing sowing dates AND cropping intensity AND variety	15.1	13.7		28.7	2.68	Variety with crop duration Much shorter than baseline + planting on day 150 and 350

S1 = rice season 1, …, S3 = rice season 3. Seasons are in order of planting date, not in order of importance. See table 3.2 for planting dates and harvest dates. RYC is the relative yield change compared with option 1.1 (eq 1)

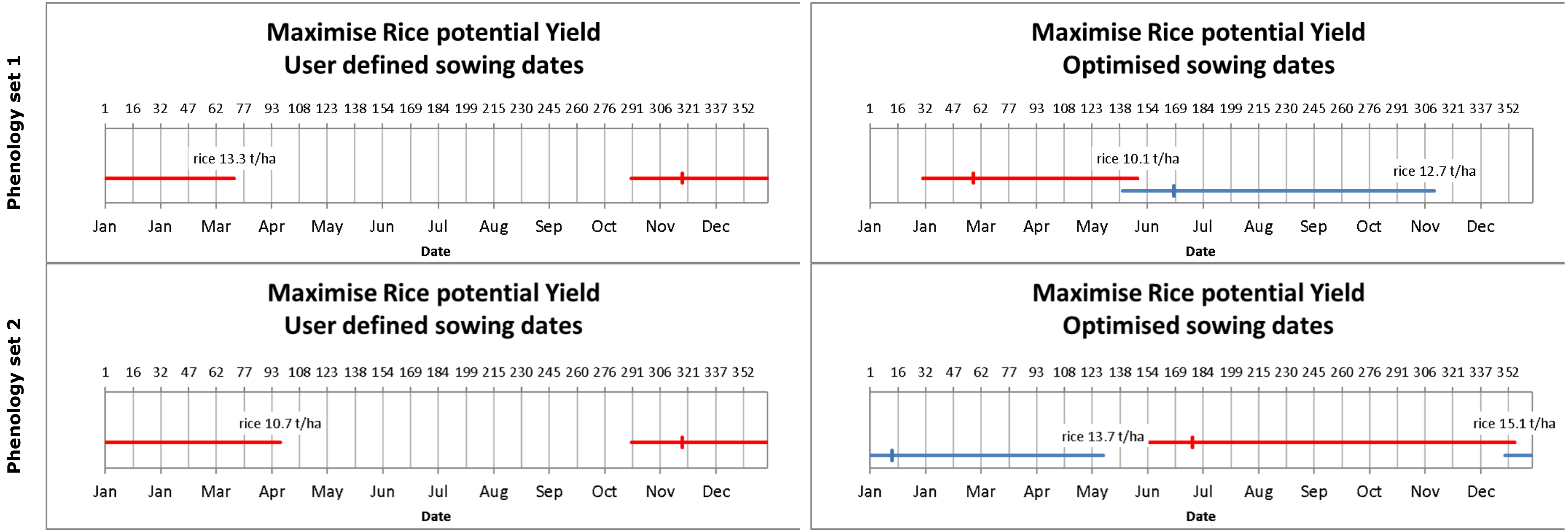

Figure 3.10 *Madagascar: Ambohibary. For two phenology parameter sets the current cropping pattern (option 1.1) and selected double cropping pattern for the future climate (around 2050, scenario RCP8.5, option 2.5 and 2.6).*

3.5 Site comparison

3.5.1 Climate change impact and adaptation options

Table 3.9 compares the sites in terms of effectiveness of adaptation options. Table 3.10 was calculated from Table 3.9 and shows ++ and -- for > 20% change, + and - for 10-20% change and 0 for when yields change less than 10% compared with the baseline.

Table 3.9 *Adaptation options for the 4 sites compared: relative yield changes.*

		Current_2000			RCP8.5_2050					
Country	Location	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	2.6
Senegal	Fanaye	1.08	1.07	1.19	0.95	1.13	1.17	1.29		1.19
Mali	Niono	1.26	1.22	1.36	0.63	0.88	1.08	1.29	0.98	0.98
Nigeria	Kano	1.45	1.25	1.57	0.72	1.18	1.11	1.49	1.03	1.42
Madagascar	Ambohibary (1)	1.11	1.05	1.15	0.70	0.81	0.97	1.02	1.71	1.95
Madagascar	Ambohibary (2)	1.00	1.05	1.05	1.44	1.46	1.60	1.64		2.68

For adaptation options o = 1.2, …, 2.6 the table shows relative yield change *RYC* compared with the baseline option o = 1.1 (eq1).

Table 3.10 *Adaptation options for the 4 sites compared.*

		Current_2000			RCP8.5_2050					
Country	Location	1.2	1.3	1.4	2.1	2.2	2.3	2.4	2.5	2.6
Senegal	Fanaye	0	0	+	0	+	+	++		+
Mali	Niono	++	++	++	--	-	0	++	0	0
Nigeria	Kano	++	++	++	--	+	+	++	0	++
Madagascar	Ambohibary (1)	+	0	+	--	-	0	0	++	++
Madagascar	Ambohibary (2)	0	0	0	++	++	++	++		++

Signs calculated from table 4.1. ++ and -- indicate > 20% change, + and - indicates 10-20% change, 0 indicates <10% change

For the current situation, the tables show for 2 sites (Niono and Kano) large possible yield gains by changing variety (option 1.2), changing sowing dates (option 1.3) and changing both sowing dates and variety (option 1.4). For the other 2 sites, Ambohibary and Fanaye, simulations showed little room for improvement.

For the future situation, climate change would have a very negative impact of -37% and -28% in Kano and Niono. A previous study showed that this negative impact is caused by reduced photosynthesis at extremely high temperatures (van Oort and Zwart, 2018), a topic that requires further investigation. In Fanaye, climate change would have a small impact of only -5%. The cause for the lesser impact in Fanaye compared with the other sites is due temperature which rises less in Fanaye than in the other sites (Table 2.4), while all sites benefit from the same increase in atmospheric CO_2 concentration (Table 2.4). These findings suggest that perhaps Fanaye is not the best site for experimental research on climate change. It might be better to conduct this research in hotter inland sites such as in Matam along the Senegal River, or along the Niger river in Mali or Niger. In Ambohibary, depending on the phenology parameters used we found either a negative impact of -30% (set 1) or a positive impact of +44% (set 2). The divergent findings in Madagascar are related to assumptions made on phenological parameters, in particular the seedbed duration, the transplanting shock and the maximum temperature for development (TMD). The sensitivity analysis showed that large uncertainty about phenological parameters translates in large uncertainty about climate change impact.

3.5.2 Intensification options

The three West-African sites differ in terms of viability of increasing cropping intensity from 2 to 3 crops per year. The reasons for the variable results between the three West African sites are (1) differences in climate and (2) crop establishment: with transplanted rice a new rice crop can already start growing in the nursery while the first crop is still in the main field. This offers the extra flexibility that can enable triple cropping. The reason why triple cropping came out as difficult and less attractive in Fanaye compared with Kano and Niono is that in Fanaye rice is direct-seeded while it is transplanted in Niono and Kano. The reason why triple cropping came out as unattractive in Niono was that part of the year becomes really too hot for rice cropping. In the future, Niono would be the hottest of the three sites.

For the Madagascar site, uncertainty about phenological parameters was too large to tell if intensification from 1 to 2 rice crops per year is an attractive option. Simulations showed that such intensification might become possible in the future (Figure 3.10, Tables 3.7 and 3.8).

3.5.3 Varieties

This study considered 4 "in-silico" varieties which were generated by multiplying DVR parameters of the baseline locally popular variety with 0.7, 0.85, 1.15 and 1.30 to obtain longer and shorter duration varieties. The phenology of these varieties was compared with phenology of 80 varieties at 5 sowing dates in Fanaye as compiled by AfricaRice in the Rice Garden Trial (RGT) dataset. For Fanaye the comparison with showed that simulated varieties are a realistic representation of actual variation that exists between varieties. The climate change scenarios suggests possible gains from changing variety. In most cases the scenarios for the three West African sites suggested shifting to longer duration varieties. From the RGT set, a number of promising long duration varieties can be identified. Observed duration from sowing to maturity for the baseline variety Sahel 108 was 121, 112, 118, 103 and 147 days, for planting days 26, 58, 72, 208 and 301 in the year 2014, with an average duration of (121+112+118+103+147)/5 = 120 days. The following 10 varieties have a much longer average duration of 145-148 days: WAB 2101-WAC3-1-TGR1-WAT B6, WAB 2094-WAC2-TGR2-B, WAB 2101-WAC1-1-TGR5-WAT B6, WAB 2094-WAC2-TGR4-B, IR 84649-21-15-1-B, WAB 2060-FKR4-WAC1-TGR5-B, Sahel 202, WAB 1572-10-B-B-FKR 4-WAC 1-1-TGR 2-WAT10-1, WAB 2098-WAC3-1-TGR1-4, FARO 57. These would be interesting varieties for further testing as adaptation options in the three West African sites.

From Madagascar also an RGT dataset with 5 sowing dates and 80 varieties was available. Within the scope of the current report it was not possible to accurately calibrate a phenology model. Further improvement to the phenology model is therefore needed and ideally parameter estimation with a larger dataset. A sensitivity analysis was conducted which showed that large uncertainty about the phenological parameters translates into large uncertainty in outcomes of climate change scenarios.

3.5.4 Sowing dates

For all sites, optimisations for the future climate change suggested large changes in sowing dates:

- For Ambohibary in Madagascar, for single rice the recommendation was sowing 100 to 110 days earlier than now;
- For Niono and Kano a shift towards planting >+70 later than now;
- For Fanaye a shift towards planting 70 days earlier than now.

In the discussion section 4.4 we will reflect on whether these changes are realistic

3.6 Trade-offs

Farmers in the study areas face constraints of timely lack of resources, therefore a certain flexibility (free days) is needed. Also, many farmers grow vegetables in the cool season and this requires availability of fields and labour during part of the year (van Oort et al., 2016). For further judgement of the adaptation options investigated here, it is important to assess if the adaptation options leave enough room for flexibility and if these options leave enough time for growing other crops. Figures 3.9 shows trade-offs between total potential yield (x-axis) and free days (y-axis), i.e. the days without rice in the main field (excl nursery). Figure 3.9 shows the current situation (1.1) and future options (2.1 to 2.6). Without adaptation (option 2.1) the length of the growing period becomes shorter, which gives more free days and lower yields (2.1 is top left of 1.1). With adaptation the length of the growing period becomes longer, which gives less free days and higher yields (downward slope).

Figure 3.9 shows triple rice would leave 60 free days in Fanaye, 75 days in Niono and 86 days in Kano (option 2.6). 86 Days in a triple cropping system is 86/3 = 28.7 days flexibility per crop. Interestingly, Kano with largest yield gains from triple cropping (option 2.6 in Tables 3.5 and 3.6) also shows greatest flexibility (86 days). Thus especially in Kano it is interesting to investigate triple rice cropping with a longer duration variety.

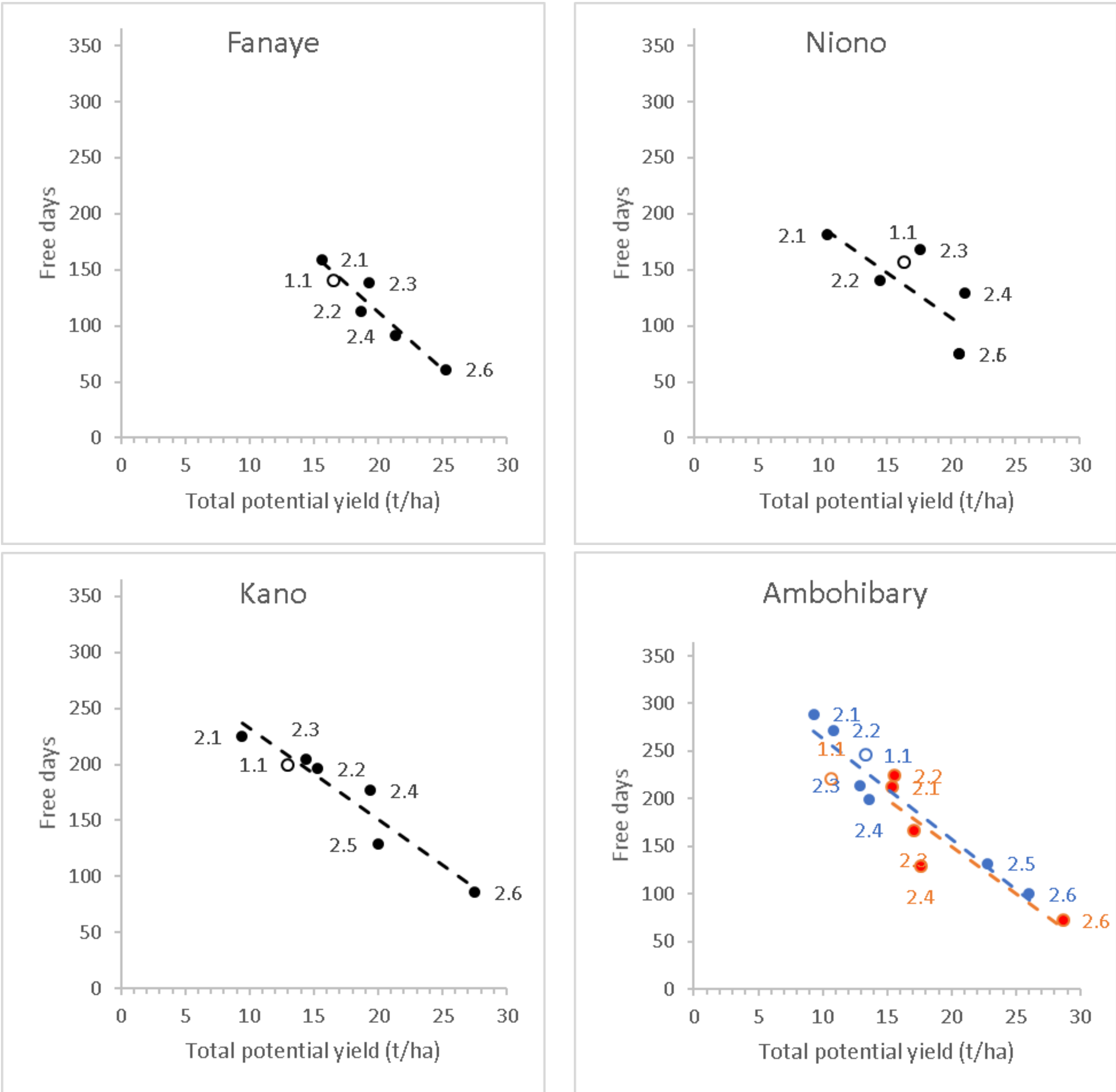

Figure 3.9 *Trade-off between free days and total potential yield for the current climate (1.1, open symbol) and for 6 adaptation options (2.1-2.6) in the future climate (around 2050, scenario RCP8.5). Free days calculated as 365 days minus total days in which rice is in the main field (excl nursery). For Ambohibary, the results of two sets of simulation results are shown, with set 1 in blue and set 2 in orange.*

Often an optimum exists in the relation between yield and the time a crop takes from sowing to maturity. A too short duration gives the crop too little time to form leaves and spikelets, which can cause a yield penalty. The yield penalty is caused by too little photosynthesis during grain filling (due to low LAI), a too short grain filling period or because too few spikelets were formed during the panicle formation phase, or a combination of these effects. These processes are simulated with the ORYZA2000 crop growth model used here (Bouman et al., 2001; van Oort et al., 2015a). For rice crops close to the optimum duration, temperature rise will make duration too short. The current study showed for all sites a yield penalty caused by shortening of the period from sowing to maturity. A too long duration can be uneconomical. Beyond a certain duration rice plants produce more leaves but it does not translate into higher yield. These processes are also simulated with the ORYZA2000 crop growth model used here (Bouman et al., 2001; van Oort et al., 2015a). Secondly, a too long duration may prohibit growing a second or third crop, or cause sub-optimal planting dates for the second or third crop. A change from double to triple rice may imply shorter growing periods for the three individual rice crops, while with a double crop there may be enough flexibility for growing two long duration rice crops. These processes are simulated with the cropping calendar construction algorithms (van Oort et al., 2016).

How to detect optimum duration at the level of a cropping calendar? Van Oort (2016) suggested a convenient way could be by calculating yield per unit time, which will be highest at the optimum duration. Figure 3.10 shows trade-offs between total potential yield (x-axis) and yield per unit time (y-axis). In Ambohibary yield per unit time decreases from option 2.1 to 2.4, suggesting that higher yield through longer duration of a single rice crop is not an attractive option. Instead, it might be more interesting to move from 1 to 2 rice crops per year (2.5 and 2.6) with a similarly high yield per unit time as in option 1.1 (> 80 kg/ha/day) but with higher total yield. The pattern is opposite in the West African sites. In Niono and Kano triple crop options 2.5 and 2.6 offer a lower yield per unit time compared with double crop option 2.4 and the triple crop options also offer less flexibility than double crop option 2.4 (Figure 3.9). This together makes triple cropping a less attractive option.

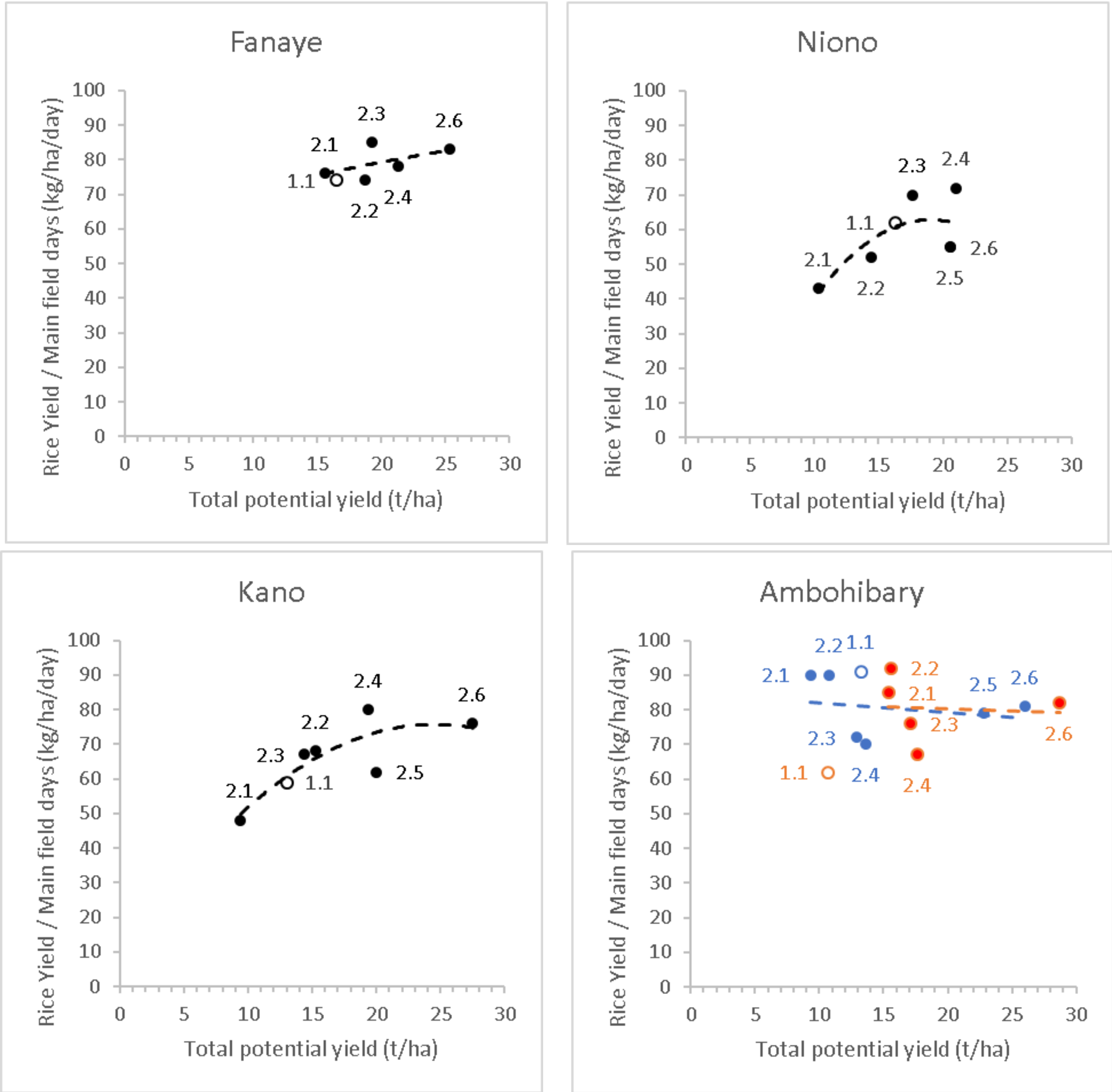

Figure 3.10 *Trade-off rice yield per unit time (= rice growing days) and total potential yield for the current climate (1.1, open symbol) and for 6 adaptation options (2.1-2.6) in the future climate (around 2050, scenario RCP8.5). Rice growing days calculated as total days in which rice is growing (incl nursery).For Ambohibary, the results of two sets of simulation results are shown, with set 1 in blue and set 2 in orange.*

4 Discussion

This discussion section presents the main findings, discusses main uncertainties and addresses two important issues not addressed in the current study: vegetable cropping and transition pathways.

4.1 Main findings

The main findings of this study are:

1. Without adaptation, climate change will have a negative impact on production
2. With adaptation, negative impact of climate change can be eliminated
3. Optimal adaptation options differ by site
4. For Ambohibary, uncertainty about phenology causes great uncertainty about climate change impact and adaptation options.

4.2 Uncertainties

This study builds on previous modelling and is therefore subject to the same limitations as already discussed by (van Oort and Zwart, 2018). In particular, the following limitations should be noted:

1. Phenology. For Ambohibary, model improvement is necessary and this will require more calibration data than the 4-5 Rice Garden Trial data considered in this report. For Kano and Niono, uncertainties that require further checking are assumptions on seedbed duration and transplating shock;
2. Cold sterility is still poorly understood (Dingkuhn et al., 2017b; van Oort and Zwart, 2018) and may well be variable between varieties. Uncertainty about cold sterility can affect the results presented in this report where shifts of sowing dates were explored;
3. Effects of extreme heat on photosynthesis are still poorly understood (van Oort and Zwart, 2018). Uncertainty about heat affects simulation accuracy regarding future heat risks in the 3 West African sites and this requires further research;
4. Where climate change scenarios show potential for increasing yields, it should be noted that to achieve higher yields, more nutrients and water will need to be taken up from the soil. The current study shows what is potentially possible. Follow-ups should consider (1) if and how sufficient water and nutrient supply can be provided and (2) if this is not possible, revise scenarios accordingly, taking into account constraints on water and nutrients.
5. The Cropping Calendar Construction (CCC) tool used here can be used also to block certain parts of the year for vegetable cropping (van Oort et al., 2016). This option was not used, due to lack of information on vegetables and their response to climate change. As such the current study shows what is best for rice. The following section presents an example of the importance of including vegetable cropping.

4.3 Vegetable cropping

In Fanaye, Senegal, both rice-rice and rice-vegetable cropping systems are found. Main vegetables are tomato and onion and these are mostly grown in the cold dry season of approximately November/December to March/April (van Oort et al., 2016). Figure 3.11 shows an example of maximisation of rice yield for Fanaye with the period from mid-November to mid-March blocked for vegetable cropping. In the current situation a rice-rice-vegetable crop is not possible. A rice-vegetable rotation is possible. With a vegetable from November to March, rice planted on day 100 (10 April) and a variety with much longer duration than the local common variety a potential yield of 10.0 t/ha would be possible. In the future the same rice-vegetable double crop would still be possible, with similar yield. A rice-rice-vegetable rotation, not possible in the current climate, might become possible in the future. Simulations showed this would require a variety with much shorter duration than the baseline variety. Which is exactly the opposite of our best options 2.2 and 2.4 (Tables 3.1 and 3.2) which proposed to shift to varieties with a much longer duration. This example shows that the choice to include vegetable crops (or other crops) will have implications for desirable rice phenological traits in a rice-based crop rotation.

In the rice-rice-vegetable scenario with a very short duration variety optimum planting dates are day 90 (30 March) and 200 (19 July). Total potential yield would be 6.9 + 6.3 = 13.2 t/ha. Compared with the current rice-vegetable system this is an increase of +31% (from 10 to 13 t/ha). Compared with the highest attainable future double rice crop yield it is a -38% yield reduction (from 21 to 13 t/ha, see Table 3.1 option 2.4).

This example shows that conclusions on which adaptation option is best are highly contingent on whether or not a vegetable is included. It affects both the recommended number of rice crops and the ideal crop duration of the rice crops. For further research, it is important to investigate the current role of vegetables and possible adaptations in the vegetable season.

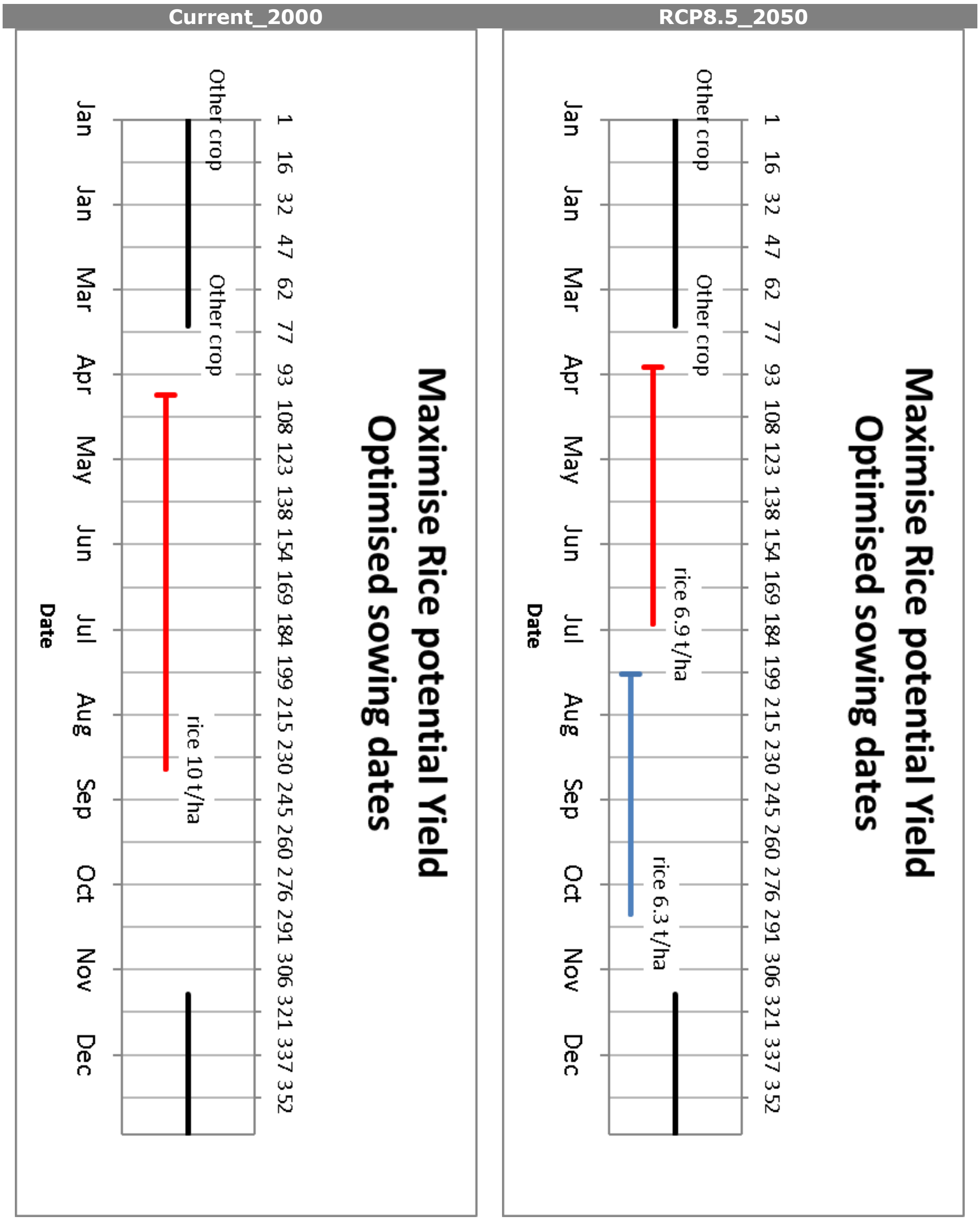

Figure 3.11 *Rice-vegetable in the current climate (around year 2000) and future climate (around 2050, scenario RCP8.5) with for the future a variety with crop duration much shorter than the local common variety.*

4.4 Transition pathways

The model based explorations suggest very large changes in sowing dates. For Ambohibary in Madagascar, the recommendation was to move to from sowing single rice on day 290 to day 180 or 190 (option 2.4 in set 1 and set 2). That is a change of more than 100 days over a period of 50 years (from 2000 to 2050). A shift of 100 days over 50 years corresponds with 20 days per decade. For Niono and Kano the recommendation was sowing 70 days later in 2050 than in 2000, a change of 14 days per decade. In Fanaye the recommendation was sowing 70 days earlier, also a change of 14 days per decade.

Are such shifts in sowing dates realistic? A review on farmers' sowing dates for various crops in Europe over a period of 50 years showed farmers sowing dates advanced by around 2.1 days per decade (Menzel et al., 2006). In the Central USA corn planting dates advanced by 4.8 days per decade (Kucharik, 2006), largely due to management and technological changes. During the same period phenology of wild plants and animals advanced faster than farmers (implying abiotic constraints for earlier start of the growing period are unlikely). During the same period experimentation and modelling showed possible yield gains from earlier planting. The advances of 2-5 days per decade were made in rich countries with much research support for farmers to guide them in their management. To realise much larger changes in sowing dates of 14-20 days per decade in the developing countries considered here will be a huge challenge. It calls for timely action to re-organise the whole logistics of planting, harvesting, availability of inputs, irrigation scheduling etcetera. To support farmers in a transition to very different sowing dates we must first understand the current decision making process. How do farmers now decide when to sow? While many other climate change adaptation studies have also shown benefits of shifting sowing dates (White et al., 2011), there is still a general lack of empirical research aimed at finding out on how farmers decide when to sow.

The proposed shifts in sowing dates are likely to be received with great skepticism by farmers and advisors. Common knowledge is that the proposed future planting dates are in fact in the current climate very risky. The future recommended sowing date day 330 (26-Nov) in Fanaye would in the current climate expose the crop to a risk of complete failure due to cold (Figure 3.2). The future recommended sowing date of day 250 (7-Sep) in Niono and Kano would in the current climate expose the crop to a risk of complete failure due to cold (Figures 3.4 and 3.6). The future recommended sowing dates of day 180 in July in the single rice option 2.4 (Tables 3.7 and 3.8) in Ambohibary would in the current climate expose the crop to a risk of complete failure due to cold (Figure 3.9). Modelling predicts the risk of cold will rapidly disappear with climate change, but it is unwise to rely exclusively on modelling. Participatory experimentation with farmers in shifting sowing dates, combined with modelling, can help farmers make the transition to strongly changed sowing dates. The transition must be made with care such that along the way, risk for farmers is kept to a minimum.

5 Conclusions

For 4 sites in Africa and for one climate change scenario (RCP8.5, year 2050), climate change impact and adaptation options were simulated a crop growth model and a cropping calendar construction model. Results suggest that farmers can adapt by changing varieties, sowing dates and in some cases the annual number of rice crops. Without adaptation climate change is projected to have a negative impact. With adaptation climate change can have an overall positive impact.

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7 Appendix

Associated with this report are 5 Microsoft Excel files:

1. File ACCRA_ScenariosResults.xlsx with tables of all the results presented in chapter 3 of the current study
2. File ACCRA_CCC_V6_MLNI_Niono_TP_SBDUR28.xlsm with all results for Niono
3. File ACCRA_CCC_V6_NGKN_Kano_TP_SBDUR28.xlsm with all results for Kano
4. File ACCRA_CCC_V6_SNFA_Fanaye_DS.xlsm with all results for Fanaye
5. File ACCRA_CCC_V6_MGAM_Ambohibary_TP_SBDUR28.xlsm with all results for Ambohibary set 1
6. File ACCRA_CCC_V6_MGAM_Ambohibary_TP_TBD10TOD18TMD42.xlsm with all results for Ambohibary, set 2

In these filenames, ACCRA refers to the ACCRA project, CCC_V6 indicates it is version 6 of the Cropping Calendar Construction file, MGAM consists of country code MG and city code AM, TP mean transplanting, DS means direct-seeding and SBDUR28 means in case of transplanting, seedbed duration was 28 days.

For illustration Figure A.1 shows a screenshot of the file ACCRA_CCC_V6_MGAM_Ambohibary_TP_SBDUR28.xlsm. The file contains the following worksheets:

- AllOptions: All possible cropping calendars for the two climate scenarios;
- ENGLISH_Userform. Sheet has is a clickbutton which opens an English userform (Figure A.2)
- Formulaire_FRANCAIS. Sheet has a clickbutton which opens a French userform
- LookupLists. Contains lists for the userforms and graphics. Don't touch this unless you know very well what you are doing
- About. Background info about the model
- "1.1 Current": results from the ACCRA project for the scenario 1.1 (see §2.5 on adaptation options)
- ...
- "2.6 Sowing + Intensity + var" : results for the scenario 2.6 (see §2.5 on adaptation options)

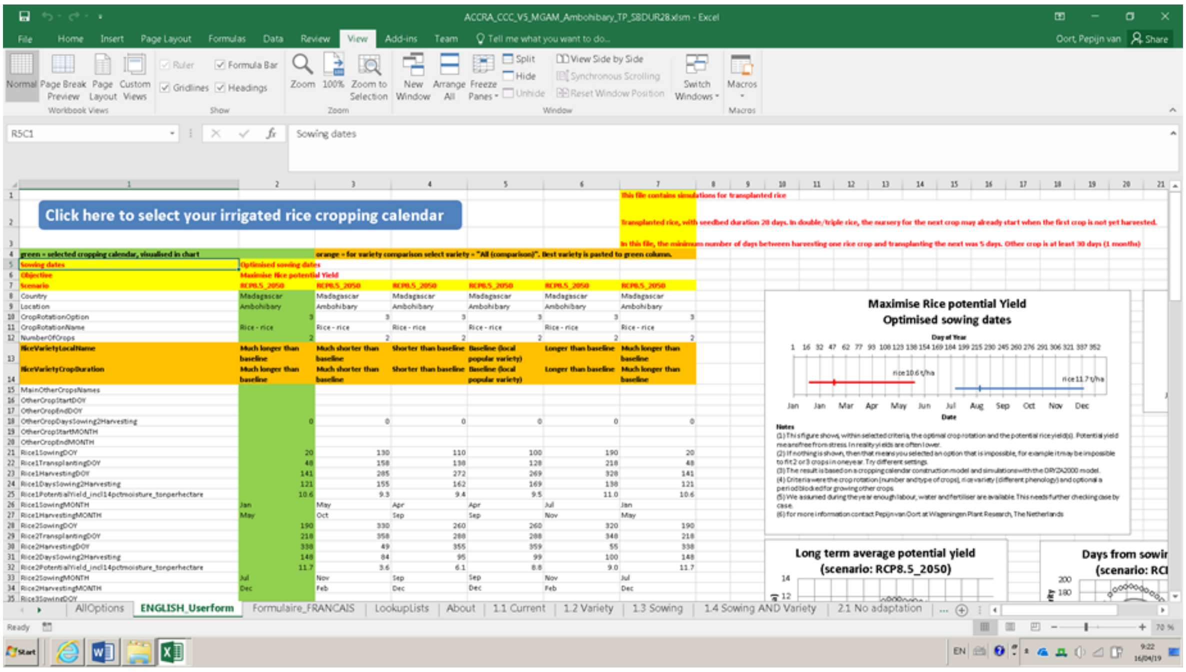

Figure A.1 *Screenshot of the ACCRA_CCC_V6_MGAM_Ambohibary_TP_SBDUR28.xlsm file.*

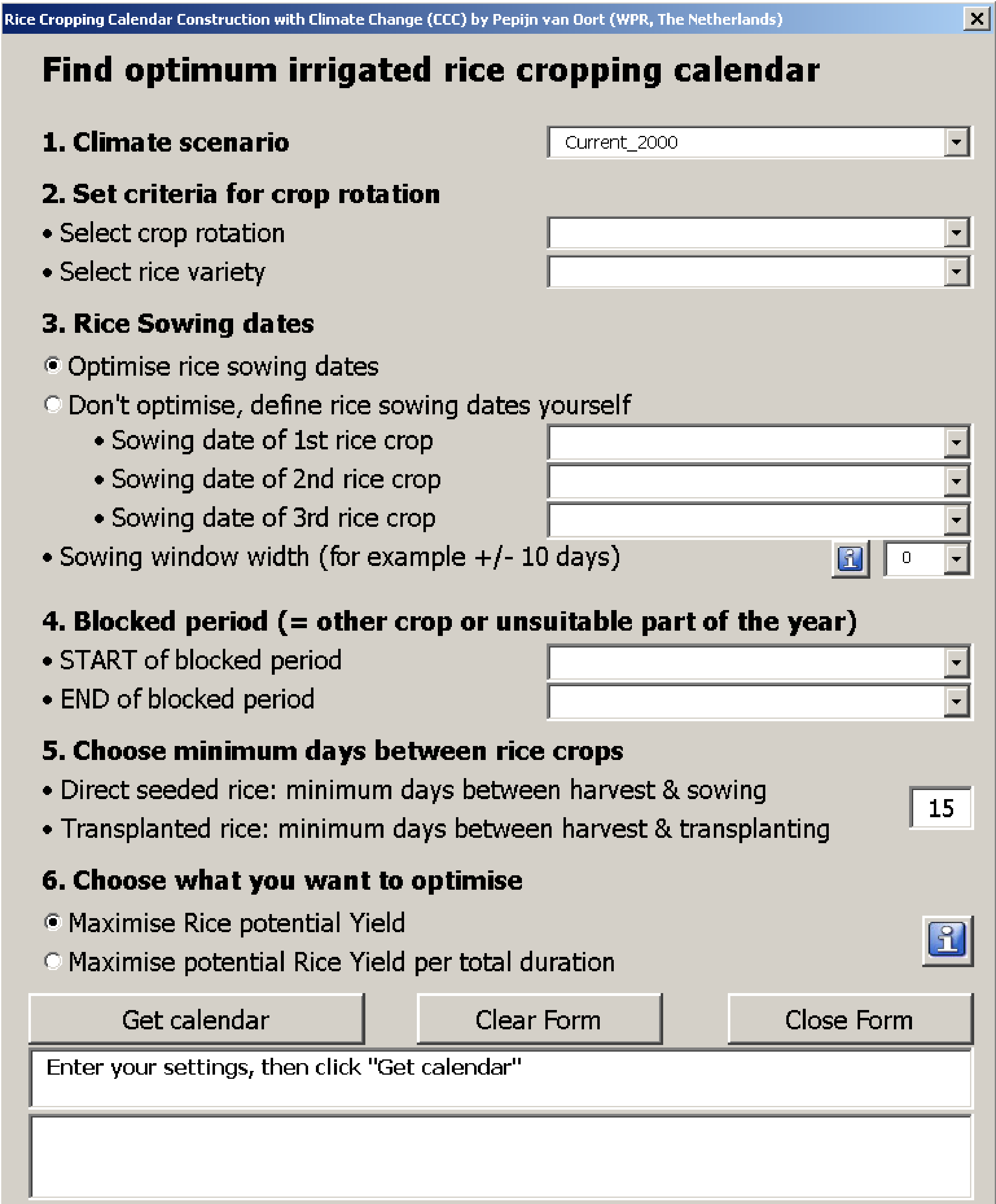

Figure A.2 *Screenshot of the user interface of a CCC file.*