Crop and Soil Final Report

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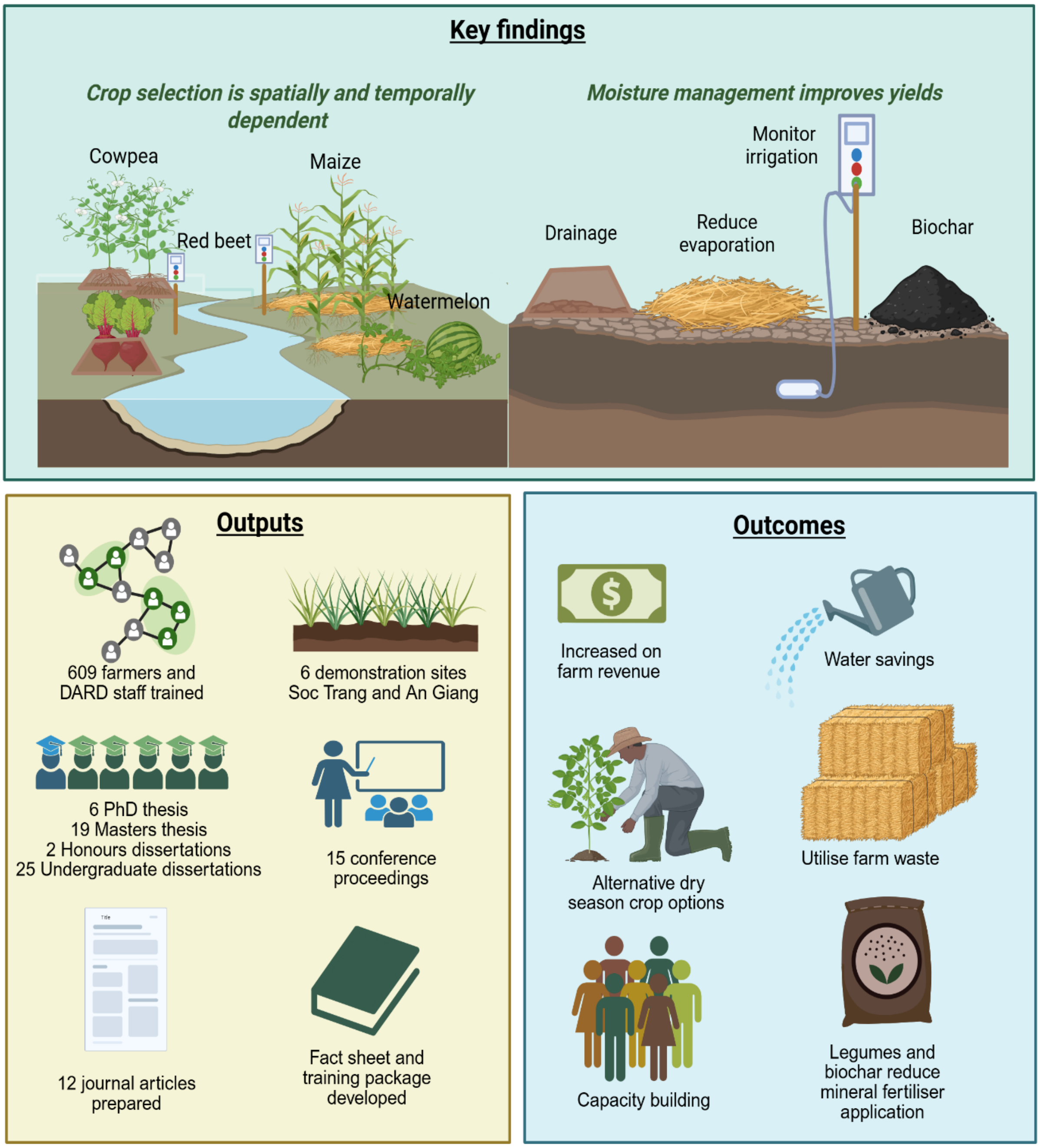

Figure 1: *Graphical abstract of the key findings, outputs and outcomes for the crop and soil component of the FOCUS project.*

Introduction

This report from the Crop and Soil Management component of the FOCUS project addresses two key objectives (Objectives 2.1 and 2.2). A combination of greenhouse, glasshouse, and field trials was employed to evaluate the suitability of alternative crops and associated management practices for production during the Mekong River Delta (MRD) dry season. The report synthesises the key experimental findings generated over the course of the project, outlining the methodology and results for each activity under the respective objectives, followed by a general discussion. Detailed descriptions of individual experiments are provided in the Appendix through published, peer-reviewed literature.

Methodology and results

Study areas

Field trial sites were established along a transect extending from the coastal areas of Lieu Tu and Long Phu in Soc Trang Province, through the low-lying region of Hau Giang, to the upstream location in An Giang Province (Figure 2). The coastal Soc Trang sites are located in the lower southern reaches of the Hau River and are characterised by low-lying, relatively flat terrain (0.4–1.5 m above sea level) and a semidiurnal tidal regime with two tidal cycles per day and an average tidal range of 0.4–1.0 m. These conditions result in pronounced salinity intrusion and freshwater shortages during the dry season.

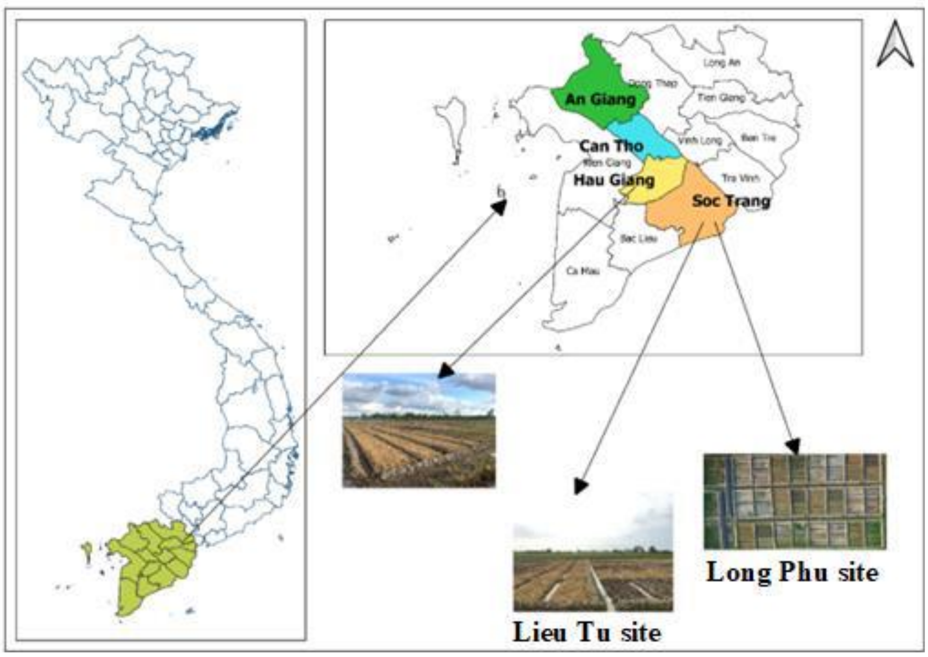

Figure 2: *Field site locations across the Mekong River Delta.*

Hau Giang represents a low-lying depression within the Mekong River Delta, with an elevation of approximately 0.21 m above sea level, making it highly susceptible to periodic waterlogging that poses a significant constraint to crop production. In contrast, An Giang is the most inland site and is characterised by larger-scale farming systems dominated by intensive double- and triple-rice cropping supported by extensive dyke infrastructure for water management; these systems require greater efficiencies, particularly in labour use and mechanisation. Results presented in this report integrate findings from all field locations, with consistent themes tested across the transect to assess the suitability of alternative crops and associated management practices within the MRD. Initial soil physicochemical properties for each site are presented in Table 1.

***Table 1**: Soil properties of the four field site locations.*

Soil properties	**Lieu Tu site**	**Long Phu site**	**Hau Giang**	**An Giang**
Sand (%)	1.50	1.60		5.70
Silt (%)	54.4	50.7		46.3
Clay (%)	44.1	47.7		48.0
Soil texture (0-15 cm)	Silty clay	Silty clay		Silty clay
Bulk density (g cm^{-3})	1.21	1.1		
$pH_{(H2O)\ 1:5}$	5.32	5.3	4.6	4.53
$EC_{1:5}$ (mS cm^{-1})	1.22	0.5	0.47	0.54
ECe (mS cm^{-1})	7.83	3.23		
Exchangeable K (cmol (+) kg^{-1})	0.62	0.66	0.44	0.50
Exchangeable Na (cmol (+) kg^{-1})	2.87	2.26	1.90	0.43
Exchangeable Ca (cmol (+) kg^{-1})	1.78	2.63	2.02	9.57
Exchangeable Mg (cmol (+) kg^{-1})	10.1	11.5	10.8	3.84
CEC (cmol (+) kg^{-1})	15.9	17.3		16.79
ESP (%)	18.0	13.1		
C total (g kg^{-1})	13.8	17.8		
N total (g kg^{-1})	1.25	1.56		
P total (g kg^{-1})	0.29	0.38		
Available N (mg kg^{-1})	31.1	20.4	41.79	9.52
Available P (mg kg^{-1})	5.04	7.73	24.1	36.9
Available Si (mg kg^{-1})	96.5	141		
	Saline–sodic soil	Slightly saline	Slightly saline	Slightly saline

Objective 2.1: Plant screening to meet requirements of the system (salinity, water use, drought stress)

Variety and species selection

A greenhouse trial in 2020/21 investigated the salinity and irrigation tolerance of cowpea, maize and watermelon varieties in a replicated (n=5) randomised block design. Salinity treatments (0, 1, 2, 4, 6 and 8 ppt NaCl solution) were applied to 8 seeds of each variety in petri dishes. Germination rates were observed and counted. Variety effected the germination of species at differing NaCl concentration. The following better-performing varieties were selected for subsequent pot and field trials: maize varieties *Future 16* and *TN 177*; watermelon variety *TN 552*; and cowpea *TN 142* and *TLP 69*.

Investigating the suitability of quinoa, cowpea and soybean to conditions of salinity and water limitation

A glasshouse trial conducted in 2020 Australia examined the suitability of quinoa (*Chenopodium quinoa* Kruso white), cowpea (*Vigna unguiculata* Red Caloona) and soybean (*Glycine max* Richmond) for growth in conditions representing of salinity and drought experienced in the MRD. Plants were irrigated with either fresh or saline (up to 4 g L^{-1}) water. Chameleon soil moisture sensors were used to trigger irrigation events, either constantly (water potential 0 to 22 kPa) or intermittently (irrigating when the water potential was below 50 kPa). Water use, soil salinity, plant performance and stress parameters were measured (Figure 3). Saline treatments significantly affected the yield of all three species; however, quinoa grew in saline conditions for the longest duration. Cowpea and quinoa tolerated irrigation with 4 g L^{-1} during reproductive phases, whilst soybean experienced leaf chlorosis and premature senescence with saline irrigation. Cowpea was negatively affected by intermittent irrigation with higher proline concentrations in younger leaves.

Chameleon sensors improved irrigation efficiency and could be used to aid farmers in developing irrigation schedules in agricultural producing regions affected by water shortages. High salinity during reproductive growth phases hindered the accuracy of the Chameleon sensors and thus their use would be most adventitious in vegetative stages to improve water use efficiency before salinity peaks. A detailed explanation of this trial is covered in the peer-reviewed paper in Kaveney *et al.* (2025).

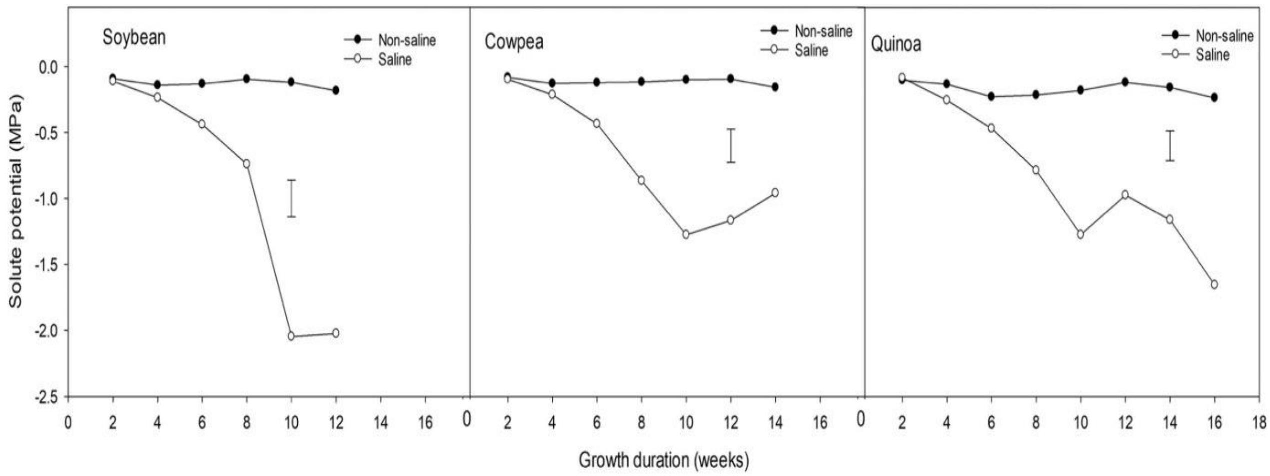

Figure 3: *Effect of non-saline and saline treatments on the soil solute potential (MPa) recorded over the growth duration of soybean, cowpea, and quinoa. Lsd bar indicates significant interaction between salinity treatments and time for each species (p = 0.05).*

Screening quinoa varieties for salinity and drought tolerance

Greenhouse and field trials were conducted in 2022/2023 to screen for saline and drought tolerant varieties of quinoa (2-want, Sluga, Titicaca, 42- test, Atlas). The soil used for the pot trial was collected from the 0-20 cm topsoil layer of a rice field in Long An Province, Vietnam. The randomised block pot experiment with 4 replications was designed to screen five quinoa varieties (2-Want, Sluga, Titicaca, 42-Test, and Atlas) under four different salinity (0, 2, 4, and 6 g/L NaCl) and two soil moisture conditions (-22 kPa and -50 kPa). The higher yielding varieties, Titicaca and 2-want, were used in a 2023 field trial investigating their response to nitrogen fertiliser rates (0, 40, 80 and 120 kg N/ha) and a 2024 sowing density trial examining sowing density and lodging.

The higher yielding varieties, Titicaca and 2-want, had lower biomass and improved water use efficiency in saline and water limited conditions (Figure 4). Titicaca displayed the greatest saline tolerance through increased yield despite being exposed to 6 g/L salt concentration and -50 kPa soil moisture irrigation conditions.

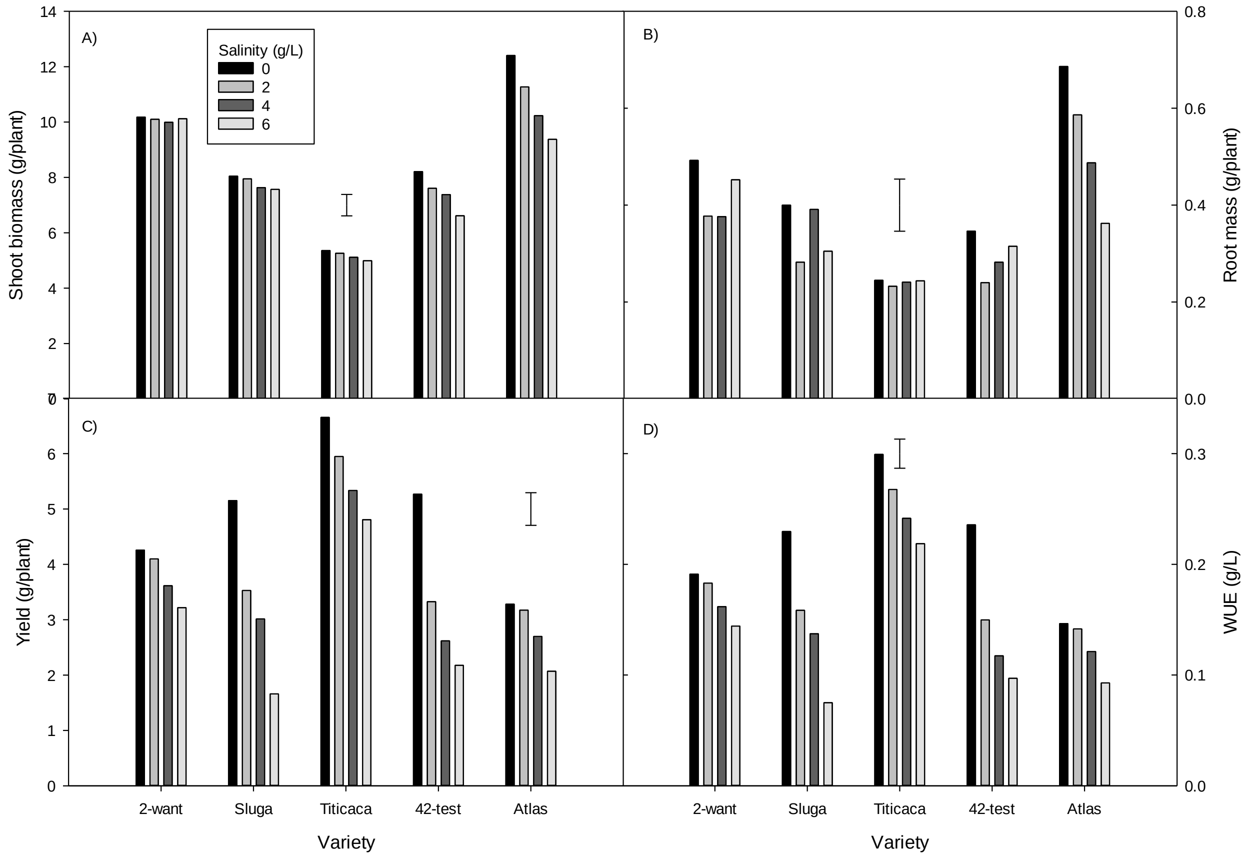

Figure 4*: The shoot biomass (g/plant), root mas (g/plant), yield (g/plant) of five quinoa varieties grown in increasing concentrations of salinity (0, 2, 4 and 6 g/L NaCl). LSD bar indicates significant interaction between salinity concentration and quinoa variety for shoot biomass, root mass, yield and water use efficiency (p=0.05).*

Nitrogen fertiliser rates of 120 kg N/ha produced the greatest biomass and yield, however lodging occurred, and the 2-want variety recorded negligible yield. Sowing densities between 15 plants/m^2 and 50 plants/m^2 had no significant effect on lodging rate. This trial also experienced an uncharacteristic heatwave during anthesis causing no measurable yield. A detailed explanation of this trial by Duong *et a*l (2026)(a) can be found in Appendix A.

Exploring the suitability of cowpea as an alternative dry season crop to rice in the Mekong River Delta, Vietnam

Two field experiments were conducted over a three-year period to evaluate the suitability of cowpea varieties for cultivation in the MRD. The trials were undertaken during the dry season at a field site in Lieu Tu Commune, Tran De District, Soc Trang Province. Traditional farmer irrigation practices were compared with continuous and intermittent irrigation regimes, with irrigation scheduling for the latter two treatments guided by Chameleon soil moisture sensors.

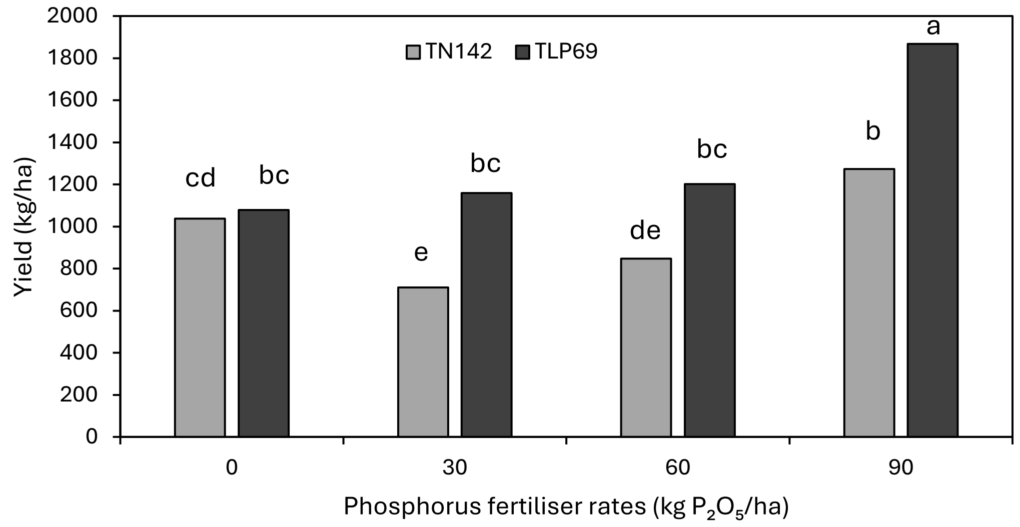

Figure 5: *The effects of phosphorus fertiliser application in a 2023 field trial at Soc Trang on the yield of two different cowpea varieties (TN142 and TLP69). Columns with differing letters are significantly different in yield (p=0.05).*

The effects of phosphorus (P) fertilisation on two cowpea varieties were assessed in experiments conducted at the same site during the 2023 dry season (February–May 2023) and the 2024 dry season (February–June 2024). Single superphosphate was applied at four rates: 0, 30, 60, and 90 kg P_2O_5 ha^{-1}.

The three irrigation methods (continuous, intermittent, and farmer practice) did not significantly affect plant biomass for either cowpea variety. However, grain yield was higher under the farmer-practice irrigation treatment compared with the continuous and intermittent irrigation treatments (Figure 5). In contrast, cowpea exhibited a clear positive response to P application, with both plant biomass and yield increasing with P rate. The highest application rate (90 kg P_2O_5 ha^{-1}) resulted in the greatest dry biomass and yield. A detailed explanation of this trial by Duong *et a*l (2026)(b) can be found in Appendix A.

Objective 2.2: Test soil management and agronomic practices that may limit the effect of salinisation

The assessment of a range of alternative crops—including red beet, watermelon, maize, soybean, cowpea, and quinoa—was conducted over five years of dry-season trials, together with evaluations of associated crop and soil management practices. Management practices such as rice straw mulch, raised beds, biochar, and Chameleon soil moisture sensors were implemented to reduce the effects of salinisation, enhance yield and water use efficiency, while reducing fertiliser inputs. Exploration of these crops and management practices often occurred in greenhouse trials before being implemented in the field. For the purposes of this report, experiments are presented according to major thematic areas, with detailed descriptions of individual trials and results provided in the Appendix as part of published peer-reviewed articles.

The investigation of alternative crops and the use of rice straw mulch

Field experiments were conducted between 2021 and 2025 in Long Phu and Tran De districts, Soc Trang Province, where dry-season salinity intrusion and freshwater shortages commonly occur, within an upland crop–rice–rice cropping sequence. Experiments were established using a split-plot design with various crop treatments (red beet, maize, soybean/cowpea, watermelon, quinoa, and fallow) and four rice-straw mulching rates (0, 3.5, 7.0, and 10.5 t ha^{-1}), with three replications per treatment. Soil and plant samples were collected throughout the growing season and at harvest for analysis.

Crop growth and yield

Straw mulching at rates of 7.0 and 10.5 t ha^{-1} were generally more effective than lower rates in improving crop growth and yield. However, the 7.0 t ha^{-1} rate was consistently more effective and stable across maize, cowpea, and red beet grown on saline-affected soils. This mulching rate significantly enhanced plant height, SPAD index, biomass accumulation, and marketable yield. In some cases, higher mulching rates (10.5 t ha^{-1}) resulted in additional yield increases (e.g. cowpea in Table 2), but responses were less consistent across crops, sites, and seasons.

Table 2: *Cowpea SPAD and yield response to mulching rates at Long Phu over the 2025 and 2023 dry season.*

	2025	2023

Mulching rate	SPAD (μmol/m^2)	Yield ($^{t\ ha-1}$)	SPAD (μmol/m^2)	Yield ($^{t\ ha-1}$)
0 $^{t\ ha-1}$	29.4^c	5.3^b	38.20^c	5.67^b
3.5 $^{t\ ha-1}$	39.5^b	5.3^b	44.67^{bc}	6.07^b
7 $^{t\ ha-1}$	41.3^b	7.2^b	46.20^{ab}	8.20^a
10.5 $^{t\ ha-1}$	46.3^a	14.9^a	51.87^a	9.70^a

Multi-season field trials focusing on red beet and maize were conducted across three sites with contrasting elevations: Long My (0.21 m above mean sea level), Lieu Tu (0.80 m), and Long Phu (0.96 m). Both crops were successfully produced (Figure 6), achieving commercial yields of up to 42 t ha^{-1} for red beet and 5.4 t ha^{-1} for maize. Straw mulching increased marketable yields by up to 114% for red beet and 49% for maize, reduced Na^+ concentrations in shoot tissues at harvest by 19% and 37%, respectively, and decreased topsoil (0–15 cm) salinity ($EC_{1:5}$) by approximately 13%. Across sites and seasons, mulch effects on crop performance were maximised at the 7.0 t ha^{-1} application rate. Analysis of relationships between soil salinity at different depths and crop yield, together with mulch response patterns, suggested that red beet rooting depth may have been more constrained than that of maize. Very shallow water tables (approximately 20 cm below the soil surface) were identified as the likely factor limiting root development in red beet under these conditions. A detailed explanation of this trial is covered in the paper by Dang Duy *et al* (2026) in Appendix A.

Figure 6: *The production of red beet and maize from a farm at Long Phu after utilising rice straw mulching.*

Soil improvement

Higher straw mulching rates (7.0–10.5 t ha^{-1}) were more effective in improving soil quality by increasing soil organic matter content, reducing soil electrical conductivity, maintaining soil moisture, and enhancing post-harvest soil conditions. Soil incubation experiments using harvested soils demonstrated that mulching at 7.0 t ha^{-1} consistently resulted in the highest microbial respiration rates and the greatest release of available nitrogen (Figure 7), indicating improved soil nutrient-supplying capacity for subsequent crops. In contrast, the highest mulching rate (10.5 t ha^{-1}) did not consistently provide additional benefits. Improvements in available phosphorus were less consistent and appeared to be site dependent.

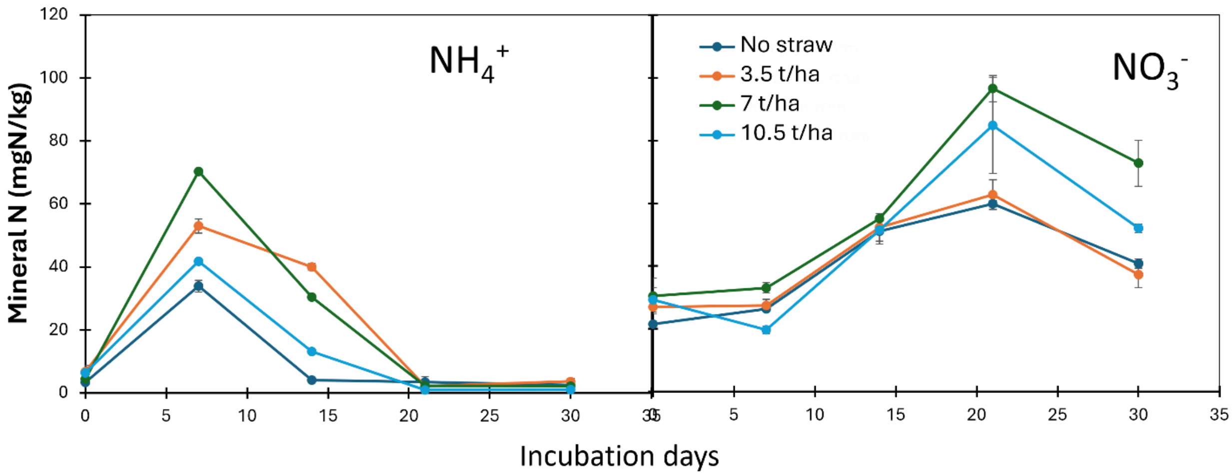

Figure 7: *The mineral N concentration (NH_4^+ and NO_3^-) of soil grown with cowpea under four different mulching rates (no straw, 3.5 $^{t\ ha-1}$, 7 $^{t\ ha-1}$ and 10.5 $^{t\ ha-1}$).*

The effects of mulching and biochar amendments were investigated across a wide range of trials conducted throughout the duration of the project, including numerous undergraduate and postgraduate dissertations and theses that utilised the FOCUS field sites for research. These studies generated a substantial and diverse body of experimental results, which are summarised in Table 3. Further details of the mulching trials are provided in Nhein *et al* (2025)a, Nhein *et al* (2025)b, Nhein *et al* (2025)c and Appendix A.

***Table 3**: A summary of the key findings from experiments conducted across Long Phu, Tran De and Hau Giang investigating mulching rates, alternative crops and biochar.*

Year	Crop	Management	Results and key findings
			Long Phu Soc Trang Province
2022	Red beet	Mulching rates	Straw mulching at 7 or 10.5 t ha^{-1} enhanced plant height and leaf length, and markedly improved the yield of red beet. Straw mulching at a rate of 10.5 t ha^{-1} significantly reduced soil electrical conductivity (EC), increased soil organic matter content and improved soil moisture.
	Quinoa, red beet and maize	Mulching rates and salinity levels (0, 2 and 4 g L^{-1}). Incubation trial.	Using 7 t ha^{-1}, quinoa demonstrated the greatest salinity tolerance, maintaining stable growth and yield under 4 g L^{-1} saline irrigation and soil ECe exceeding 15 dS m^{-1}. Beetroot's yield was not significantly different under 2 g L^{-1} saline irrigation with straw mulching. Maize was impacted by the high heat and humidity, even in non-saline conditions. Across treatments, rice straw mulching significantly reduced soil ECe, Sol-Na^{+}, and ESP, and improved crop performance under saline irrigation.
2023	Maize	Mulching rates	Yield and growth parameters of maize, including plant height, SPAD index, biomass, grain yield, and proline content, further confirmed that straw mulching at 7 t ha^{-1} was the most appropriate treatment. Maize yield under straw mulching at 7.0 t ha^{-1} reached 5.47 t ha^{-1}, which was higher than that of the non-mulched treatment (3.78 t ha^{-1}). Mulching rates from 7 t ha^{-1} reduced soil electrical conductivity (EC), maintained soil moisture, and increased soil organic matter content, available nitrogen, and available phosphorus.
2023	Maize, Cowpea	Mulching: focusing on the incubation of harvested soils	Mulching at 7 and 10 t ha^{-1} significantly improved plant height, leaf length, fresh biomass, dry biomass, and yield of both crops grown on saline-affected soils. Nutrient analysis at harvest showed mulching reduced soil electrical conductivity (EC), increased soil pH, and enhanced soil organic matter content, as well as available nitrogen. The 7 t ha^{-1} straw mulching released the highest amount of nitrogen and phosphorus and exhibited the highest microbial respiration, indicating greater microbial activity.
2023	Cowpea	Biochar: focusing on the incubation of harvested soils	The application of biochar at a rate of 5 t ha^{-1} did not alter soil pH, electrical conductivity (EC), or soil organic matter content. Experiments evaluating nitrogen and phosphorus release and microbial respiration showed that straw mulching at 7 t ha^{-1} increased soil organic matter, enhanced microbial activity, and increased the release of NH_4^{+} and NO_3^{-} from saline-affected soils after cowpea cultivation. The addition of biochar at 5 t ha^{-1} further promoted microbial activity in the soil following cowpea cultivation. The activities of urease and phosphatase enzymes tended to increase; however, no statistically significant differences were observed between straw mulching at 7 t ha^{-1} alone and the combined application of straw mulching (7 t ha^{-1}) and biochar (5 t ha^{-1}).
2025	Cowpea	Mulching rates	Straw mulching improved several soil properties, including soil pH, soil moisture retention, and soil organic matter content. Cowpea grown on straw-mulched soil at rates of 7 t ha^{-1} or higher showed significant improvements in plant length, SPAD index, biomass, and yield. The highest yield was obtained at a mulching rate of 10.5 t ha^{-1}, reaching 14.9 t ha^{-1}, compared with 5.3 t ha^{-1} in the non-mulched treatment.

2025	Red beet , maize, okra	Demonstration applying Chameleon	Combining straw mulching with the Chameleon soil moisture sensor in the cultivation of red beet , maize, and okra reduced irrigation water use by 38–50% compared with the farmers' practice of irrigating twice per day. Soil chemical properties, including pH_{H2O}, EC (1:5), available nitrogen, available phosphorus, cation exchange capacity (CEC), and exchangeable and soluble Na^+ and K^+, did not differ between the two irrigation methods. Crop yields were also not significantly different between the two irrigation strategies. The Chameleon sensor enabled accurate determination of irrigation timing, reduced both the amount and frequency of irrigation, and still met crop water requirements for optimal growth.
		Tran De	
2023	Maize, cowpea	Mulching: focusing on the incubation of harvested soils	For maize growth, straw mulching at rates of 7 and 10.5 t ha^{-1} improved fresh biomass, dry biomass, and grain yield. For cowpea, straw mulching at 7 t ha^{-1} was the most effective treatment in enhancing the SPAD index and yield. Nutrient analysis at the end of the cropping season indicated that straw mulching did not markedly alter soil chemical properties, except for an increase in soil organic matter content. Straw mulching had a positive effect on soil microbial respiration post-harvest and increased the release of available nitrogen, with the 7 t ha^{-1} mulching rate showing the greatest effectiveness. In contrast, the potential supply of available phosphorus was not improved under the different straw mulching rates.
2023	Cowpea	Biochar: focusing on the incubation of harvested soils	The incorporation of 7 t ha^{-1} of straw into the soil increased soil organic matter content, enhanced microbial activity, and increased available nitrogen and available phosphorus in saline-affected soils in Tran De district, Soc Trang province. Biochar application promoted the release of NH_4^+ but did not increase NO_3^- concentrations, and it tended to improve soil chemical properties. Soil incubation experiments further indicated that microbial respiration was correlated with soil organic matter content as well as the potential release of nitrogen and phosphorus.
		Hau Giang	
2023	Maize, watermelon		The use of organic amendments at different straw mulching rates did not alter soil pH or soil moisture. The application of organic materials was effective in promoting watermelon growth and enabled a 25% reduction in chemical fertilizer use. Straw mulching at 7 t ha^{-1} increased soil NH_4^+ concentrations and inhibited the nitrification process. Overall, these results indicate that the appropriate use of straw mulching combined with biochar and compost application has potential for improving soil chemical properties and reducing chemical fertilizer inputs by 25%.

Impacts of rice straw on soil silicon

In Vietnam, silicon (Si) accumulator crops like rice and maize crops are commonly rotated, but rice straw is often removed for animal feed. A study assessed whether rice straw mulch could improve soil available Si and maize growth using: (1) a laboratory-scale incubation experiment to investigate the short-term effects of different organic and inorganic amendments on selected soil chemical properties and Si fractionation, and (2) a long-term field experiment to assess the effects of rice straw mulching on soil Si availability and maize growth in a rice–maize rotation system under salt-affected conditions. Four rice straw mulch levels (0, 3.5, 7, and 10.5 t ha^{-1}) were applied during the maize growing season (Feb–Apr) and repeated for three years. At the lower available Si field, rice straw mulch significantly increased the phosphate buffer-Si, $CaCl_2$-Si and H_2O_2-Si in soil two weeks after sowing whereas the higher available Si field showed no differences among treatments. In contrast, the Si concentration in maize stems and leaves increased notably in the higher rice straw treatments at both sites. Furthermore, a negative correlation was found between Si and Na concentrations in the maize stems and leaves, suggesting that Si may play a role in mitigating Na uptake and reducing Na toxicity. Details of this study can be found in Huyen et al (2025).

Rice crop yield following upland crop production

Farmer observations of substantial increases in rice yield following the cultivation of upland crops provided the catalyst for quantifying the effects of different upland crops and mulching rates on subsequent rice production. Table 4 shows that all upland crops resulted in significantly higher rice yields compared with fallow treatments, particularly at higher mulch application rates. As a result of these findings (Dang Duy *et al.* 2026- Appendix A), the effects of mulching rates on soil biological properties were further investigated under the partner SRA project Soil MICRO (SLAM/ 2022/175) and can be found in the paper in Appendix A by Nguyen Van *et al.* (2026).

Table 4: *The yield of the following rice crop following alternative upland crops. Differing letters in the same column are significantly different p=0.05*

Treatment	Red beet -rice	Watermelon-rice	Maize-rice
Fallow	2.91 c	2.91 c	2.91 b
No mulching	4.00 b	3.83 b	4.03 a
3.5 t ha^{-1}	4.25 a	4.10 ab	4.12 a
7 t ha^{-1}	4.12 ab	4.19 a	4.14 a
10.5 t ha^{-1}	4.13 ab	4.11 ab	4.04 a

The use of biochar and compost as a soil ameliorant

Biochar was applied to field trials alongside mulching. Biochar application at 5 t ha^{-1} showed supportive rather than dominant effects on soil properties and nutrient dynamics.

- Biochar did not significantly alter soil pH, EC, or soil organic matter content in the short term.
- However, biochar enhanced microbial activity, particularly when combined with straw mulching, and promoted the release of NH_4^+, while its effect on NO_3^- formation was limited, suggesting a potential role in moderating nitrification/nitrogen retention.

- Enzyme activities (urease and phosphatase) tended to increase with biochar addition, although differences were not statistically significant.

Overall, biochar was most effective when applied in combination with straw mulching, contributing to improved post-harvest nutrient dynamics and supporting soil biological activity, rather than directly increasing crop yield or altering basic soil chemical properties.

Improving water use efficiency through irrigation management

The Chameleon soil moisture sensor (Chameleon sensor) is a simple and low-cost tool designed to support irrigation decision-making based on soil water status (VIA, 2023). The sensor provides a colour-based indication of soil moisture tension (blue = wet, green = adequate, red = dry), allowing farmers to determine when irrigation is required without complex calculations or advanced technical knowledge. This approach is particularly useful for improving water use efficiency (WUE) when combined with management practices such as mulching, which reduces soil evaporation and helps maintain stable soil moisture in the root zone.

Greenhouse trials utilising soil from field sites were conducted to evaluate the potential of Chameleon soil moisture sensors to reduce saline irrigation and improve water-use efficiency in red beet. Two irrigation treatments—conventional scheduling and sensor-based irrigation—were combined with three salinity treatments (non-saline, 0.5 g L^{-1}, and 1 g L^{-1} NaCl) and applied to red beet (*Bohan F1*). Results indicated that utilising Chameleons significantly reduced water use without compromising the yield of red beet (Figure 8). Detailed results are published in the paper Cao Dinh *et al* 2025.

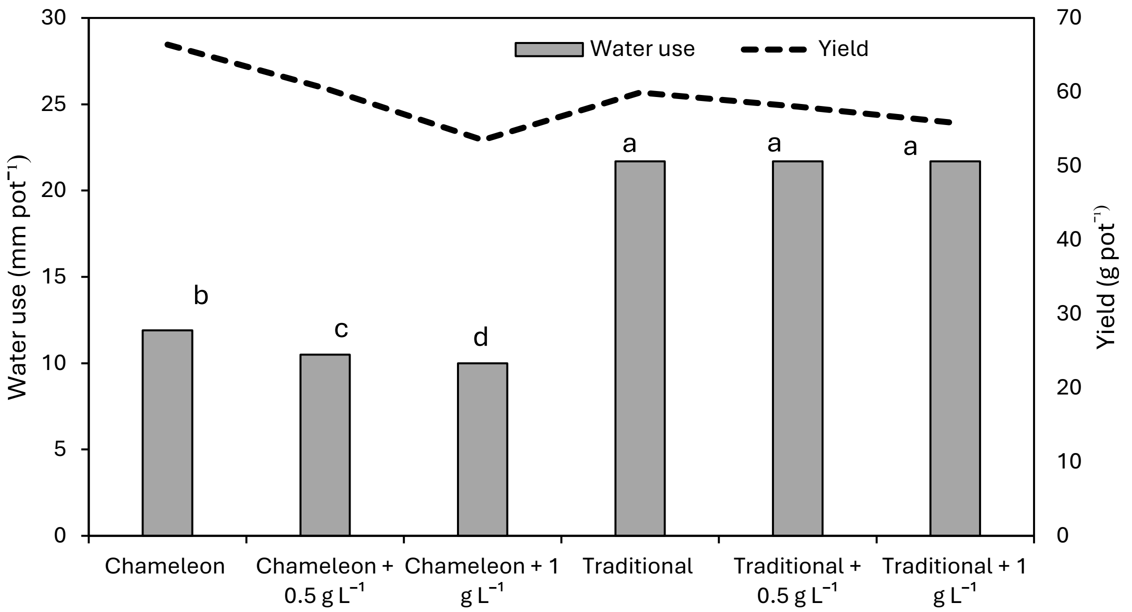

Figure 8: *The total water use and yield of red beet grown with (Chameleon) or without (Traditional) irrigation monitoring combined with saline (non-saline, 0.5 g L^{-1} or 1 g L^{-1}). Differing letters on the columns (water use) indicate significant difference p=0.05.*

Chameleon soil moisture sensors were regularly installed in upland crop field trials in Soc Trang, MRD. Irrigation as determined by the Chameleon treatments were compared to farmer-controlled irrigation schedules with and without straw mulching (Figure 9). A range of upland crops were grown including watermelon and beetroot, and the yield, soil moisture status and water use via flow meters was recorded. The use of Chameleons and mulching saved 43% water compared to farmer determined irrigation treatments, with no compromise occurring for the yield of beetroots. Similarly, watermelons irrigated with Chameleons saved 58% water compared to farmer irrigation, with labour savings meaning irrigation occurred every 4-5 days instead of daily.

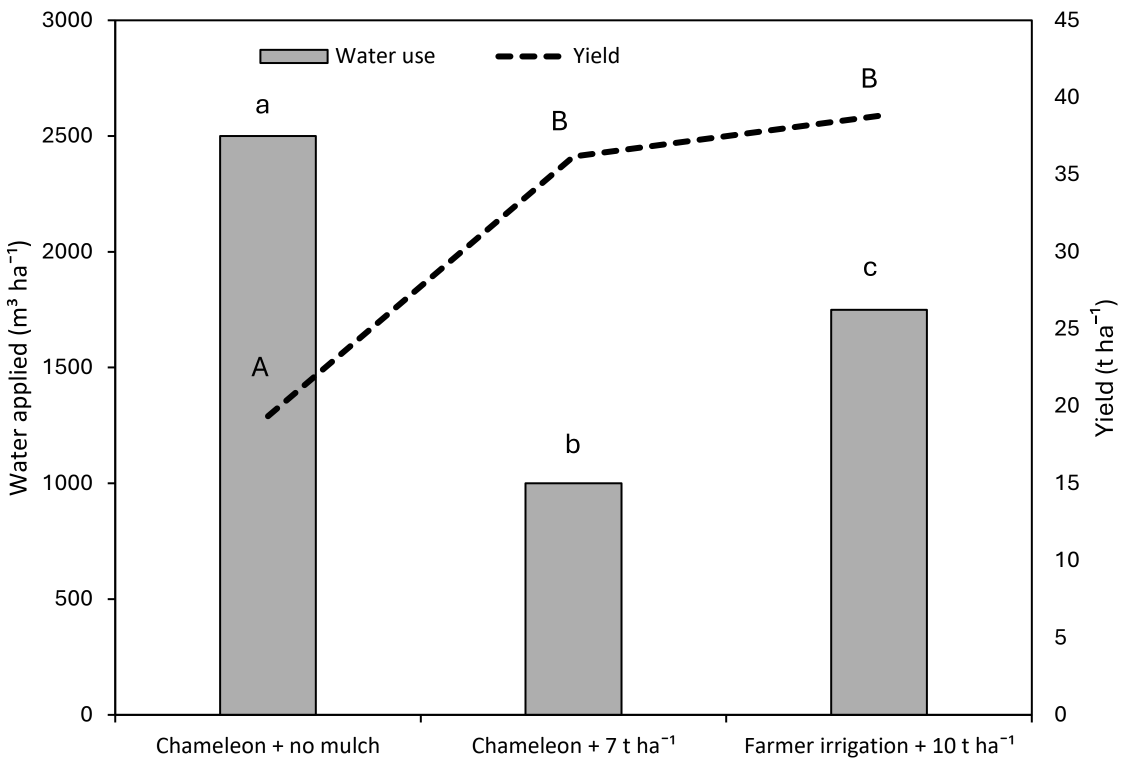

Figure 9: *The quantity of irrigation water applied and consequential yield for a red beet crop grown at Long Phu, Soc Trang Province in 2022 comparing treatments using a Chameleon with no mulch, a Chameleon with 7 t ha^{-1} rice straw mulch and traditional farmer irrigation with 10 t ha^{-1}. Differing letters (uppercase for yield, lowercase for water use) are signifncantly different p=0.05.*

Farmers praised the reductions in labour and fuel (water pump usage) when Chameleons were used in conjunction with mulching (Table 5). One farmer from Soc Trang stated that he had more time for looking after his grandchildren after growing upland crops with Chameleons (ACIAR newsletter).

Table 5: *labour and fuel consumption for the growth of upland crops using various irrigation methods including Chameleon sensor–based irrigation at Long Phu, Soc Trang (2022).*

Crop	Treatment	Labour (hrs/ha)	Fuel (L)
Maize	Chameleon + non-mulching	1230	492
	Chameleon + mulching 7 $^{t\ ha-1}$	697	278.8
	Conventional irrigation + mulching 10.5 ^{t} ha-1	820	328
Watermelon	Chameleon + non-mulching	820	328
	Chameleon + mulching 7 $^{t\ ha-1}$	273	109
	Conventional irrigation + mulching 10.5 ^{t} ha-1	410	164
Red beet	Chameleon + non-mulching	2904	1161
	Chameleon + mulching 7 $^{t\ ha-1}$	1298	519
	Conventional irrigation + mulching 10.5 ^{t} ha-1	1776	710

Two on-farm trials were conducted in Thoai Son District, An Giang Province, to assess the potential of Chameleon sensor–based irrigation to reduce water use in cucumber and edamame soybean production. The cucumber pilot trial was implemented continuously over three cropping seasons from December 2021 to November 2022, while the edamame soybean trial was conducted within a single rice–soybean–rice rotation.

Each trial consisted of two treatments:
(i) irrigation guided by Chameleon sensors combined with straw mulching at 7 t ha^{-1}; and
(ii) irrigation based on farmer experience combined with conventional straw mulching (9 t ha^{-1} for cucumber) or no mulching (for edamame soybean).

Chameleon sensor-based irrigation combined with straw mulching markedly reduced irrigation water use compared with farmers' practices without yield penalties (Table 6). In cucumber, irrigation water decreased by 48%, while yield remained comparable. Similarly, in edamame soybean, irrigation water was reduced from by 33% with similar yields. These results demonstrate the potential of Chameleon-guided irrigation to improve water-use efficiency while maintaining crop productivity.

Table 6: The dynamic of irrigation water use, water saving, and yield of cucumber under Chameleon-based irrigation and farmers' practice with rice-straw mulching in An Giang province during 3 crop seasons in 2022.

Treatment	Amount of water applied (m^3/ha)	Amount of water save (%)	Yield (tons/ha)
Cucumber			
Chameleon + mulching 7 tons/ha rice straw	870±10.3	~48%	61±4.12
Farmers' monitoring + mulching 9 tons/ha rice straw	1660±8.99	-	62±3.77
Soybean			
Chameleon + mulching 7 tons/ha rice straw	1580	33%	5.76±3.01
Farmers' monitoring + non-mulching	2350	-	5.62±1.71

Values are means ± SD calculated across three consecutive cucumber cropping seasons (Dec 2021–Nov 2022).

Changing sowing date calendar

Investigation into changing sowing dates was initiated following repeated field trial crop losses, where plant reproductive stages coincided with peak salinity, heat, and drought stress toward the end of the dry season. Repeated trials comparing early (late December/January), mid (February), and late (March) sowing times were conducted for selected crops.

Early sowing increases the risk of waterlogging, particularly when rice harvest is delayed due to a prolonged wet season. In addition, surrounding fields that remain under rice flood irrigation, with bund heights exceeding those of adjacent upland crop fields, further elevate the risk of waterlogging during germination and early establishment.

Mid-season sowing (February) is agronomically optimal. Waterlogging risks during germination and seedling establishment are reduced, and peak abiotic stresses during the reproductive phase have not yet occurred. However, the timing coincides with Tet (Vietnamese Lunar New Year), when labour availability is significantly reduced. As a result, February sowing does not align well with the production schedules and cultural priorities of farming households in the Mekong River Delta (MRD) (Figure 10).

Late sowing (Late February/ March) avoids both waterlogging risks and labour shortages associated with Tet. However, crops begin to encounter salinity, drought, and high temperatures during vegetative growth, with stress intensifying and peaking during the reproductive stage, increasing the risk of yield loss.

Adjustments to the dry-season cropping calendar to avoid abiotic stress exposure are complex. Decisions must balance agronomic risks, seasonal climate variability, irrigation management in surrounding rice systems, labour availability, and cultural considerations. Further research to optimise timing, investigate triggers and priorities for farmer decision making processes, and market influence is required.

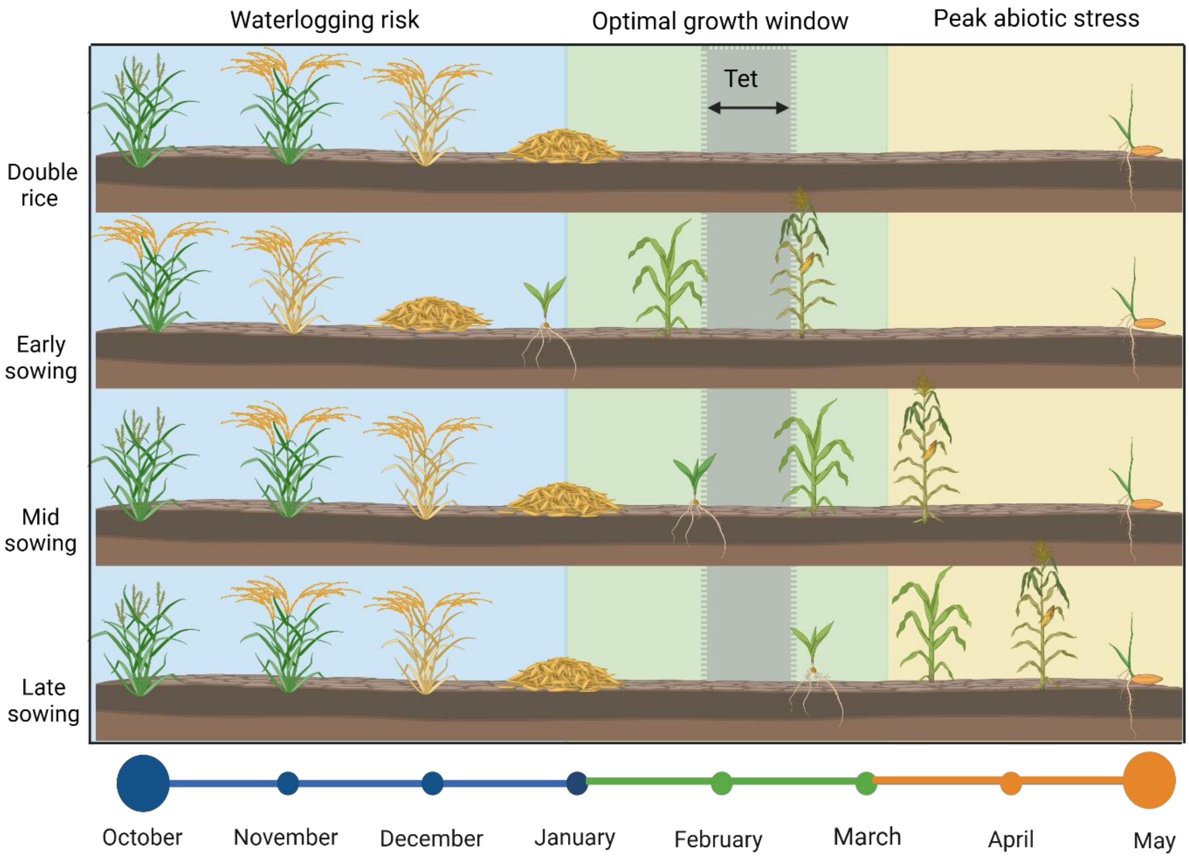

***Figure 10**: An example of changes (early, mid, late) to the sowing dates of an upland crop (Maize) and its lifecycle in relation to the previous and following rice crops, peak abiotic stresses (temperature, salinity and water shortages) and cultural events (Tet holidays).*

Economic value of alternative crops

The cost and profit data (Table 7) recorded from the trial conducted in Long Phu, Soc Trang during the 2022 dry season indicate that the tested upland crops achieved higher economic efficiency than rice cultivation and involved lower risk associated with the use of saline irrigation water. This is attributed to the shorter growing period of upland crops and their lower irrigation water requirements than rice. The percentage increases in economic efficiency and profit for the different crop cultivation models are presented in Tables 7.

Table 7: *Economic efficiency between rice and other crops during the 2022 dry season in Long Phu – Soc Trang (unit: VND). Note: Assuming the initial economic efficiency of rice cultivation is 0%*

	Rice	**Beetroot**	**Maize**	**Watermelon**
Yield	5.7 t ha^{-1}	40 t ha^{-1}	20,160 fruit	5.9 t ha^{-1}
Price/ unit	5,100đ	8,000đ	10,000đ/3 fruits	11,000đ/kg
Total cost	13,080,000	58,632,000	46,404,000	36,850,000
Total income	29,070,000	320,000,000	67,200,000	64,900,000
Profit	15,990,000	261,368,000	20,796,000	28,050,000
Profit increase (%)	**0%**	**163%**	**25%**	**75%**

General discussion

Crop selection and associated management practices

The following general discussion examines the alternative crops and management practices evaluated in this project. It is important to acknowledge that many other suitable alternative crops and management options exist; however, the scope of this project focused on understanding the processes of implementation and adoption within a production system traditionally dominated by rice and largely unfamiliar with upland cropping systems.

The performance of upland crops was highly dependent on both spatial and temporal factors. Abiotic stresses—including salinity, water availability, temperature extremes, and waterlogging—varied across MRD trial sites and generally intensified as the dry season progressed, peaking in April and May. Associated management practices, such as mulching, irrigation monitoring, biochar application, and the use of raised beds, had significant positive effects on yield, water-use efficiency, and farmer revenue, and were generally well received by local farmers.

Cowpea

Cowpea (*Vigna unguiculata*) is a legume of significant agricultural value, providing a high-protein food source for both human and livestock consumption. Its ability to fix atmospheric nitrogen also delivers important system-level benefits by improving soil fertility and reducing reliance on synthetic nitrogen fertilisers (Mndzebele et al., 2020). Cowpea has traditionally been cultivated in marginal production environments due to its resilience to abiotic stresses such as drought and low soil fertility (Bawa, 2020, Karikari et al., 2015); however, prior to this study, it had not been grown in the Mekong River Delta (MRD). Cowpea was successfully grown across multiple trial sites and dry seasons. It proved responsive to phosphorus application (Figure 5) with variety selection proving important in

Figure 11*: Nodulation on a cowpea plant at a trial site in Soc Trang, 2024.*

maximising yield. The comparatively high yield of TLP69, even in the absence of applied P, shows how potential varietal differences in P-use efficiency could be exploited in breeding and management strategies for low-input systems in the MRD. The low availability of quality cowpea seed inoculant in Vietnam is a constraint to optimising production and maximising the nitrogen fixing benefits of cowpea. However, active nodulation was observed in plants (Figure 11), particularly on sites where repeat plantings of cowpea had occurred over two or more seasons. The integration of legumes into a rice cropping system may help famers reduce fertiliser applications and meet the governments one million hectares of sustainable rice production targets.

Labour requirements of cowpea has been identified as an issue of concern by farmers. Whilst cowpea is suitable for the conditions of the delta and provides benefits to subsequent, it requires harvest daily or every second day, which farmers do not like. Farmers have seen the benefit of incorporating legumes into their rotations and have shown interest in alternative low labour legumes. The cost and benefits of legume inclusion, in particular cowpea, require better understanding to identify if cowpea is suitable for scaling out.

Red beet

Red beet is widely regarded as both a drought- and salinity-tolerant crop, possessing a range of physiological mechanisms that enable tolerance to abiotic stress (Yolcu et al., 2021). Findings from the present field trials support this characterisation, with red beet demonstrating high salinity tolerance and water-use efficiency while generating the highest revenue among the crops evaluated. Field trials conducted during the 2021/22 dry season indicated that red beet production generated an estimated revenue of VND 261 million ha^{-1}, compared with an average of VND 10–15 million ha^{-1} from rice cultivation. This represents a substantial increase in profitability, even after accounting for input and labour costs.

Red beet yields were highly responsive to rice straw mulching, with yield increases of 114% at Long Phu and 56% at Lieu Tu. However, waterlogging was identified as a key constraint to red beet production. The adoption of raised beds and careful site selection, particularly avoiding low-lying areas, significantly improved plant establishment and overall performance. Red beet establishment was also negatively affected by extreme heat events during the 2023 season, a stress factor not encountered in earlier years of the field trials. In response, sowing dates were shifted earlier in the planting calendar to avoid peak temperatures. Nevertheless, further research is required to optimise sowing times that balance avoidance of extreme heat, potential waterlogging associated with an extended rainy season, and practical constraints such as rice harvest schedules and major cultural events, including the Tet holiday.

Maize

Maize was consistently grown throughout the duration of the project and demonstrated tolerance to saline conditions and moderate drought stress. Although maize exhibits only moderate salinity tolerance and is particularly sensitive to salt stress during early growth and reproductive stages (Ahmed et al., 2017), appropriate management practices substantially improved performance. Elevated soil salinity can reduce germination, restrict root development, and impair photosynthesis, leading to yield losses (Baghel et al., 2019); however, the use of mulching significantly mitigated these effects. Mulching increased maize yields by nearly 50%, with yield gains of up to 5.4 t ha^{-1}.

Maize has relatively high water-use efficiency compared with many other cereal crops but remains sensitive to water deficits during tasselling and grain filling (Farooq et al., 2015). When Chameleon sensors and mulching were used in combination, irrigation water use was reduced by up to 70% without compromising yield. Consequently, maize is best suited to environments with moderate salinity where reliable soil moisture can be maintained through effective soil and water management. Maize production was relatively profitable for farmers, achieving approximately a 25% increase in returns compared with rice; however, heat stress was identified as a key limitation to maize growth.

Quinoa

Quinoa is a water use efficient halophyte (Abbas et al., 2023) that was investigated as an alternative crop option to rice or fallow in the dry season. The novelty of growing quinoa in the delta required an understanding of variety selection and crop optimisation in conditions experienced in the dry season. Successfully cultivating quinoa in saline and water-limited areas of the Mekong River Delta (MRD) requires the use of varieties that can tolerate these stresses while still producing economically viable yields. Field trials conducted during the 2022 and 2023 dry seasons demonstrated that the variety *Titicaca* exhibited the greatest tolerance to salinity, maintaining performance under salt concentrations of up to 6 g L^{-1} and soil moisture conditions of approximately −50 kPa (Duong *et al* (2026)(a) Appendix A). Glasshouse experiments proved that quinoa had the lowest daily consumption of water and was unaffected by intermittent irrigation compared to soybean and cowpea. Evidence of salinity tolerance mechanisms in quinoa, especially during reproductive phases, included leaf proline accumulation and a reduction in K/Na ratios to partition Na^{+} away from young leaves (Kaveney et al., 2025). However, the field results also highlighted substantial challenges for quinoa production under real-world MRD conditions. Although grain yield increased with nitrogen application, lodging occurred across a range of sowing densities, indicating structural limitations under intensive management. Quinoa yield was particularly negatively affected by high temperatures. These findings suggest that further research is required to identify suitable technical solutions, including adjustments to the cropping calendar to minimise exposure to abiotic stresses during sensitive reproductive stages such as anthesis. By aligning flowering and grain filling with periods of lower temperature stress, quinoa varieties such as *Titicaca* may offer a viable alternative to rice during the dry season in the MRD. Mechanisation of sowing and harvest will also need development for it to be successfully integrated into the broadacre rice production systems.

Soybean

Farmers became familiar with growing soybean in the MRD as popular vegetable crops (Khai and Yabe, 2011) after the Ministry for Agricultural and Rural Development (MARD) developed a land-use plan (2014–2020) to encourage the shift from intensive rice production to alternative cropping systems (Nguyen et al., 2020). Soybean was evaluated in Australian glasshouse experiments and earlier field trials; however, it showed poor tolerance to saline and dry conditions. Early senescence and plant mortality were observed in both environments, leading to the exclusion of soybean from further salinity-affected field trials and its relocation to upstream sites in An Giang Province.

At these inland locations, soybean growth demonstrated a 33% reduction in irrigation water use when Chameleon sensors and straw mulching were applied in combination. Although unsuitable for saline-affected areas, soybean may represent a viable alternative crop for inland provinces, particularly given its nitrogen-fixing capacity, which could contribute to reduced mineral nitrogen fertiliser requirements in rice-based cropping systems.

Watermelon

Watermelon was examined in early screening and field trials to be moderately saline tolerant. Watermelon is generally classified as moderately sensitive to soil and water salinity, with yield and fruit quality declining as salinity increases, particularly during germination, early vegetative growth, and flowering (Kaur et al., 2025). Salinity stress can reduce vine growth, impair nutrient uptake, and limit fruit set; however, watermelon has a relatively deep and extensive root system that allows it to utilise soil moisture efficiently under well-managed conditions. While the crop has high water demand during flowering and fruit expansion, its overall water-use efficiency can be improved through practices such as mulching, and careful irrigation scheduling. A yield increase of up to 75% occurred from mulch application of 7 t ha^{-1}. Farmers growing watermelon earnt VND 28 million ha^{-1}, more than double that of rice production, meaning watermelon may be suitable for growth in areas not limited by dry-season water shortages i.e. further inland up the MRD river.

Figure 12: *In a clockwise direction starting from the top left: Maize grown with straw mulch, farmer using Chameleon in the field, watermelon harvest, measuring red beet, soybean growing in An Giang, cowpea on a trellis, pot trials in Can Tho glasshouse, Long Phu field site.*

Management practices

Implementing various management techniques can provide a cost-effective way to reduce the effects of salinity and maximise production of dry season alternative crops. Conserving soil moisture, monitoring irrigation, and establishing effective drainage are well proven management options that can be used in conjunction with a suitable replacement crop to maximise production.

Mulch

Mulching with organic materials is an effective way to maintain soil moisture (Abd El-Mageed et al., 2016), reduce evaporation (Fu et al., 2018), slow capillary rise and reduce the concentration of surface salt (Song et al., 2020). Straw mulch is a cheap, biodegradable soil covering method that has been used by many producers throughout Asia to limit the effects of salinity (Kaveney et al., 2023). In Vietnam, straw represents an environmentally friendly alternative to black plastic mulch, which is commonly used but presents disposal and sustainability challenges.

Field trials (Figure 13) conducted under the FOCUS programme confirmed that crop production can be optimised at a straw mulch rate of 7 t ha^{-1}. Consistent yield increases were observed at this rate, with little or no additional yield benefit at the higher rate of 10.5 t ha^{-1}. Using the lower application rate therefore reduces labour requirements while maintaining comparable crop performance.

The following rice crop yield was positively affected by dry-season mulching treatments. Findings from the partner SRA project Soil MICRO (SLAM/2022/175) found significantly higher microbial biomass after cowpea was grown with straw mulch and biochar at the field site at Soc Trang. Rice straw mulch is rich in carbon and plays a pivotal role in nutrient cycling in soil microbial systems. The addition of these amendments can stimulate microbial activity and create a priming effect (Pan et al., 2016). Mulching helps retain soil water, regulate temperature and improve soil structure (Mazuecos-Aguilera et al., 2024) and the addition of straw mulch in paddy-upland cropping systems increases microbial biomass by increasing phosphorus availability and improving the utilisation of phosphorus by soil microbes (Wang et al., 2022). The return of rice straw to the system also helps improve the chemical and physical soil properties, particularly soil organic fractions that consequently increase microbial biomass (Yan et al., 2020).

In salt-affected paddy fields where crop yield is limited by abiotic stress, soil silicon plays an important role in plant growth and stress tolerance. Under intensive rice cultivation, continuous nutrient removal through harvested biomass can lead to nutrient imbalance in soil. At the same time, rice residues, particularly rice straw—a major source of plant-available Si—are often removed from fields for other uses, which can contribute to a gradual decline in soil Si supply. In rice-based cropping systems under saline conditions, Si availability depends not only on total soil Si content but also on the input and transformation of Si through crop residues. Although no improvement in labile and moderate labile Si forms in soil by rice straw application in the field at the higher levels of soil Si content after 3 years, it is necessary to consider the Si loss from cultivation activities annually. A rice crop can remove from 200 to 500 kg Si ha^{-1} (Tubana et al. 2016, Guntamukkala et al. 2017). Besides that, studies on Si leaching in paddy fields showed that leaching Si can reach to more than 200 kg Si $ha^{-1}crop^{-1}$ (Nguyen et al., 2016, Takakai et al., 2025), emphasizing the need of Si supply for a sustainable Si cycle in the agricultural system. To improve soil available Si supply and enhance crop tolerance, the study emphasized the necessity of rice straw returning into cropping systems affected by salinity. The results offer recommendations for using rice straw sustainably and indicate that integrating inorganic and organic Silicon sources may be a viable approach to maintaining silicon cycling and developing climate-adapted agriculture in the Mekong River Delta, Vietnam.

Figure 13: *Rice straw mulch applied to raised beds in the field trials at Hau Giang before the sowing of alternative crops.*

Biochar and organic amendments

Biochar and compost application influenced soil physicochemical properties, crop yield, and microbial activity, with effects being more pronounced when combined with straw mulching. Soil nutrition studies demonstrated that reducing mineral fertiliser inputs to 50% of standard rates, in combination with compost and biochar amendments, resulted in yield increases of approximately 13–14% compared with the use of 100% fertiliser rates alone. Biochar creates favourable microenvironments for microbial growth by supplying carbon and nutrients, thereby promoting microbial diversity (Bolan et al., 2024). Increased microbial biomass contributes to improved soil structural stability, enhanced nutrient cycling, and subsequent yield benefits (Gayan et al., 2023).

Straw mulching at a rate of 7 t ha^{-1} combined with biochar additions of 5 t ha^{-1} promoted the highest microbial biomass, with these beneficial effects persisting through an anaerobic rice cropping season. Mulch, compost and biochar improve soil moisture retention and soil structure, thereby enhancing water infiltration and soil aeration (Tang et al., 2021, Zhang et al., 2024). These conditions are favourable for aerobic nitrifiers (Long et al., 2017) and also increase substrate availability for microbial activity (Abdo et al., 2022). Biochar contributes substantial organic matter inputs to soil systems (Tang et al., 2021), while upland crops such as cowpea further increase soil organic matter through leaf litter decomposition and root exudation. Consequently, the cultivation of upland crops with appropriate soil management practices can improve soil properties and modify microbial communities relative to leaving fields fallow. Further research is required to examine the effects of biochar on nutrient turnover, specific microbial processes including those related to C and N cycling, and greenhouse gas emissions.

Chameleon soil moisture sensors

The combined use of rice straw mulch, raised beds, and Chameleon soil moisture sensors resulted in a reduction of irrigation water use by approximately 50% without any loss in crop yield. These practices not only conserved freshwater resources during the dry season but also reduced fuel consumption and irrigation labour requirements. The associated time savings enabled farmers to reallocate labour to other farm activities or family commitments.

Chameleon soil moisture sensors supported reductions in both the frequency and volume of irrigation events by providing real-time, colour-coded indicators of soil moisture status (Figure 14). Their integration into glasshouse and field experiments demonstrated consistent benefits, with on-farm adoption leading to significant savings in water, fuel, and labour costs while maintaining yields. Overall, water use by participating farmers was effectively halved without compromising productivity.

Farmers in the MRD are highly experienced in irrigating rice paddies; however, the water requirements of upland crops differ substantially in both quantity and timing. The ability to monitor soil moisture is therefore critical for informed irrigation decision-making and improved water-use efficiency. As an affordable and user-friendly technology, Chameleon soil moisture sensors also function as an effective learning tool, helping farmers better understand upland crop water requirements while promoting more efficient and labour-saving irrigation practices. In some instances, the influence of Chameleon sensors was so strong that farmers began to align the timing of their own irrigation with that used in adjacent research trials, effectively rendering the traditional farmer irrigation practice treatment obsolete.

The practical benefits of Chameleon sensors have generated strong interest among researchers, provincial Department of Agriculture and Rural Development (DARD) staff, and farmers, enhancing both agronomic research and extension activities. This demand has created opportunities for engagement with local suppliers to support wider adoption. At present, Chameleon sensors are manufactured in Africa and Australia; however, there is potential for establishing a South-East Asian production facility to meet growing regional demand. This is still a limitation for adoption and scale out of Chameleon use, which extends beyond the scope of the project.

***Figure 14**: A Chameleon soil moisture sensor installed in a field trial at Long Phu, Soc Trang province (left) and in a greenhouse trial at Can Tho University (right).*

Raised beds

Raised beds were implemented to improve drainage and facilitate salt leaching, thereby reducing the risk of waterlogging during germination and early establishment of upland crops. Trials were conducted at Long Phu and Hau Giang, with mixed results.

At Long Phu, raised beds were effective in enabling early sowing, supporting successful plant establishment under reduced waterlogging risk. In contrast, at Hau Giang, raised beds were inundated due to the low height of surrounding dykes, which could not holdback the higher water levels in adjacent fields. As a result, early sown crops experienced prolonged waterlogging and failed to establish.

The relative difference between dyke height and the surface of the raised bed also impacted trials testing the establishment of direct seeded rice on raised beds. At Long Phu, rice was able to be sown effectively on the raised beds formed for upland crops. However, at Hau Giang the higher raised bed, relative to the dyke, caused heavy rain to wash the rice seedlings from the bed and into the drainage furrows. It was also noted that higher beds had a greater weed burden and provided shelter for rats and other pests. Thus, engineering of raised beds and dykes need to be considered carefully if the beds are to be retained to reduce labour costs.

Case study- Mr Sol's farm

The field site at Long Phu Soc Trang Province was regularly affected by dry-season salinity and freshwater shortages. A range of upland crops (red beet , maize, cowpea and quinoa), management practices (mulch, biochar and compost) and water management practices (Chameleon irrigation vs famer irrigation) were successfully implemented on the site.

The farmer Mr Tran Kim Sol (Figure 15) typically grew rice from May until February before leaving his rice paddy as fallow during the dry season due to salinity. Mr Sol highlighted that growing upland crops was not as labour intensive as rice and allowed him more time to care for his grandchild. He highlighted the profitability of growing upland crops, particularly red beet which didn't require many inputs yet still yielded and sold well. Red beet proved 10 times more profitable than rice. Mr Sol stated in the ACIAR Vietnam's March 2022 newsletter "thanks to an introduction to upland crops and the Chameleon card from the ACIAR project, I was able to continue farming on my paddy land for 4 months in the dry season otherwise I would have to find a part-time job elsewhere'.

Figure 15: *ACIAR Vietnam country manager Nguyen Thi Thanh An, farmer Tran Kim Sol and A/prof Chau Minh Khoi at Mr Sol's farm with some red beet grown on saline soil, March 2022. Photo courtesy ACIAR Vietnam Newsletter.*

Cropping calendar and associated risks

The dry season in the MRD typically extends from December to May, during which salinity levels progressively increase and reach their peak toward the end of the season (Figure 16). Salinity of canal water rises over this period, and soil salinisation intensifies in the later months of the dry season (Kotera et al., 2014). Crops with shorter growing durations have the potential to complete their life cycles before peak salinity occurs, whereas longer-duration crops require a high level of salt tolerance during their reproductive phase, which coincides with the period of highest salinity stress.

Crop diversification involving upland crops in rotation with rice necessitates adjustments to existing cropping calendars to avoid these peak abiotic stresses. In some instances (e.g. Hau Giang field trials in 2021/22 and Soc Trang in 2022/23), these adjustments resulted in crops being exposed to unforeseen environmental stressors such as waterlogging or heat stress, reflecting increasing climate variability. This creates two key risks for farmers: (i) upland crop failure due to exposure to environmental stress, a risk similar to that already faced under traditional rice-based systems; and (ii) the possibility that successful outcomes in a given year may be driven by favourable but atypical weather conditions that may not recur in subsequent seasons.

Additional risks associated with diversification and cropping calendar changes were observed during the establishment of demonstration sites in 2022/23, where irrigation practices in neighbouring fields caused waterlogging that prevented sowing at the selected site. This highlights the importance of considering local hydrology, market pressures and landscape-scale water management in decision-making around crop diversification.

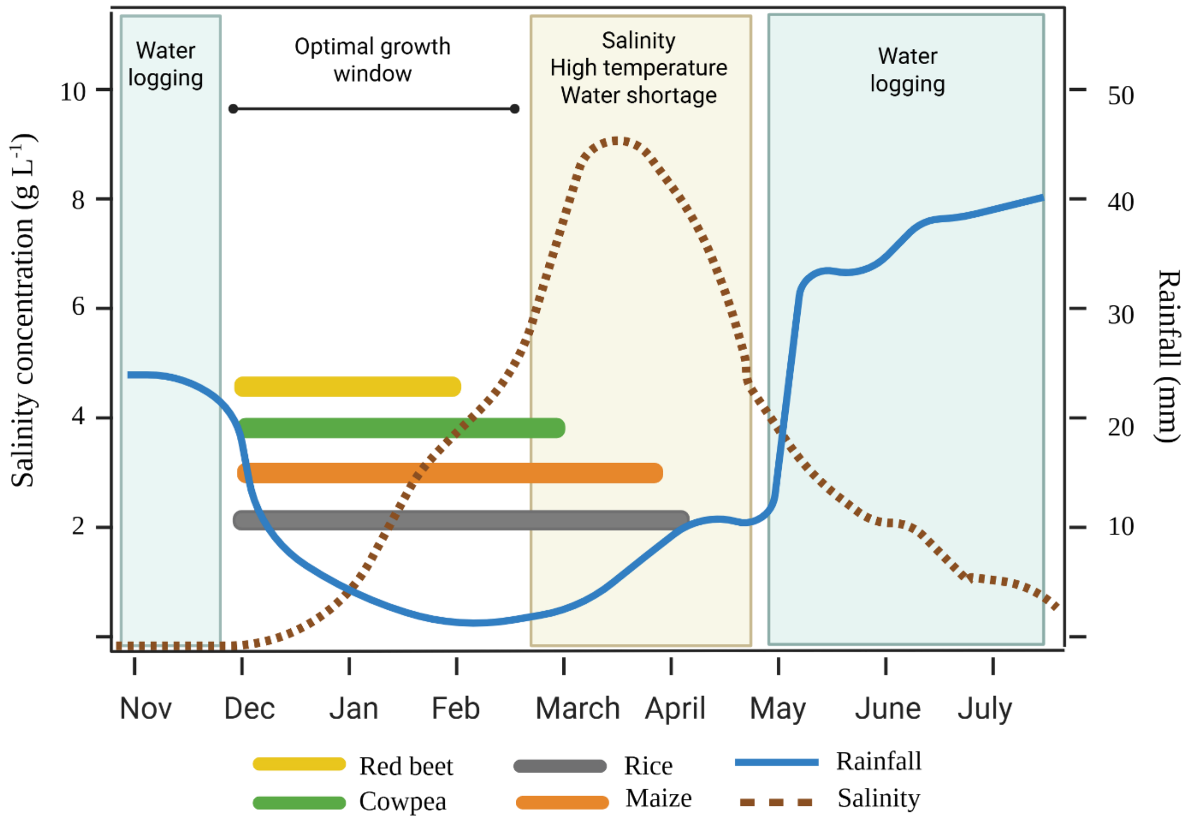

Figure 16: *An example of how alternative crop growth duration fits in the dry season amongst abiotic stresses including waterlogging, extreme temperatures, salinity and water shortages. Image from Kaveney et al. (2023).*

Risk to end users

The project team recognises the need for transparent communication with farmers regarding the risks associated with adopting new crops and management practices. Farmers have raised concerns regarding financial risks, particularly for those who borrow money to cover input costs and use land-use rights or leases as collateral. Further exploration of how the integration of basic financial literacy and risk management training into crop diversification extension packages is required. The project has also examined the potential benefits of advancing the timing of rice crops to allow subsequent upland crops to avoid the most severe drought and salinity conditions of the dry season. However, such changes introduce additional risks; for example, severe storm events caused significant damage to early crop growth in one province. Increasing rainfall variability remains a major challenge for crop-based production systems in the Mekong Delta.

Key recommendations and conclusions

Crop suitability is spatially and temporally dependant e.g. Salt sensitive crops are not suitable for the lower delta but can provide productive and profitable options further upstream.

7 t ha^{-1} rice straw mulch, and 5 t ha^{-1} biochar are optimal rates to improve plant productivity and reduce abiotic stresses.

Irrigation management with Chameleons can halve water use without yield compromise, especially when combined with mulching.

Alternative crops can be very profitable (up to 163 times greater than rice).

It is recommended that opportunities to expand distribution of chameleons are investigated by Australian/Vietnamese governments

Cowpea formed good nodulation despite no innoculation, indicating promising options for legume introduction into the cropping rotation and to decrease N fertiliser use.

Crops with labour and production constraints (e.g. cowpea and quinoa) require further optimisation for MRD field conditions.

Timing of sowing windows are very important to avoid abiotic stresses but changes are risky and complicated by agronomic, social and cultural factors.

Research gaps

Further explore the effects of biochar on soil and plant growth e.g. microbial processes, nutrient cycling and greenhouse gas emissions.

Conduct a cost benefit analysis of incorporating legumes into a rice-upland cropping system e.g. fertiliser efficiencies, labour, soil microbial changes.

Optimise time of sowing for alternative crops.

Examine sequestration potential of soils in the MRD under alternative cropping systems to rice.

Generate baseline greenhouse gas emissions from rice-upland crops and determine how management changes this.

Investigate soil microbial dynamics under the implementation of upland crops and associated management practices.

Intervention strategies need to be tested to improve farmer confidence in markets.

Fertiliser efficiencies and nutrient requirements need to be investigated for new crops and mulch conditions.

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Appendix A- publication list

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(a) Nhien, C. T., An Giang, C. D., Kaveney, B., Condon, J., Khanh, T. D., Minh, D. D., Long, N. V., Loc, N. V., & Khoi, C. M. (2025). Growth and yield responses of maize, beetroot, and quinoa to salinity and straw mulching. *Plant, Soil and Environment*, *71*(10), 681-694. https://doi.org/10.17221/317/2025-PSE

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