Research article

On-farm Effects of Subsurface Drainage System on Chinese Cabbage (*Brassica pekinensis* L. Rupr.) Production in Rainy Season at Svay Rieng Province, Cambodia

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Abstract Vegetable production in Cambodia is unstable during the rainy season due to saturated soil conditions, leaving the comparative market advantage to neighboring Vietnam and Thailand. One potential solution that has been proposed is the introduction of a Subsurface Drainage (SD) system, as elucidated in our previous studies. In the current study, SD systems was installed on plots of Chinese cabbage in Svay Chrum District, Svay Rieng Province, to determine their potential in increasing the production period and productivity during the rainy season. The treatments consisted of three SD systems within three growing conditions (GC) including open-field, plastic house, and net house including five replications with a total of 45 plots. The results of the experiment showed positive improvement in terms of growth and yield of Chinese cabbage at a rate of 15% and 22% for SD2 and SD3 systems respectively; and 58% and 66% for net house and plastic house conditions, respectively. The extension of the production period from intermittent to year-round is of great benefit to vegetable producers, and will lead to improved market connections and better production margins, stabilizing income generation. However, the analysis still excluded the cost-effectiveness and efficiency of the experiment due to the absence of detailed data on expenditures, including the cost of drainage pipes, construction of the net and plastic houses, and water consumption.

Keywords on-farm, subsurface drainage (SD), Chinese cabbage, rainy season

INTRODUCTION

Agriculture is an important mainstay of the Cambodian economy to lift many people out of poverty. In 2021, the share of agriculture in Cambodia's gross domestic product (GDP) was 22.85%, including the contributions of fishery at approximately 5.5%, livestock at 2.6%, forestry at 1.6%, and crops at about 13% (MAFF, 2021). Although the major occupation of the Cambodians is agriculture, the country is a net agricultural importer, giving vegetable imports worth approximately USD 200 million annually (Thira et al., 2020). The heavy reliance of the country on neighboring countries' vegetables is associated with the highly seasonal productions of Cambodian producers lasting for around only three months from late December to late March. The period is appropriate for vegetable production as the weather is relatively mild and dry (Wandschneider et al., 2019). Moreover, rice farmers are free from rice production and some of them opt to produce vegetables for additional income, causing the volume of vegetables to reach a peak while the price falls to the lowest one (IRL, 2007). After the period, water becomes scarce and the soil becomes too dry whereas the wet season faces the problem of too much rainfall, causing waterlogging, high pests, and diseases (Wandschneider et al., 2019). The discontinuous supply of vegetables at stable volume has caused the vegetable value chain to break and loss of competitiveness to the neighboring countries, namely Vietnam and Thailand. It is reported that local capacity for vegetable production could supply approximately 45% of the market demand and 70% is in the peak period of the production in dry season (CPS, 2019). A wide variety of vegetables was cultivated across the country, including leafy, stem, and fruit-bearing, root, bulb, tuberous, leguminous green vegetables, etc. Fruit-bearing vegetables were planted on 35,000 ha; leafy and stem vegetables on almost 6,000 ha. Vegetables are increasingly recognized as essential for food and nutritional security. Vegetable production is a key component of farm diversification strategies to provide a promising economic opportunity for reducing rural poverty and unemployment in developing countries (Pepijn et al., 2018). Chinese cabbage (*Brassica pekinensis* L. Rupr.) is annually grown as a salad crop. It is indigenous to China and eastern Asia, where it has been in cultivation since the fifth century. Two more or less distinct species of Chinese cabbage are grown. The leaves are long, dark green, and oblong or oval, and they do not form a solid head. It is also called Chinese mustard (Kalloo et al., 1993). Chinese cabbage (*Brassica pekinensis* L. Rupr.) is a popular leafy vegetable of Cambodian farmers and consumers among many kinds of vegetables for their daily food security and income generation (Um Raingsey, 2015). The drainage system provides substantial benefits to agricultural production which could contribute to (i) increasing farm income, (ii) intensification and diversification of cropping; and (iii) generation of employment (Datta et al., 2004). Proper management of irrigation practices could provide various benefits to crop production such as extended crop season, increased yield, and improved aeration of the root zone. However, the development of drainage systems has been lagging far behind the development of irrigation, leaving agriculture at a high risk of losing productive lands due to waterlogging and salinization (Abdel, 2000). There is no exception for Cambodia where the introduction of Subsurface irrigation systems has been very limited and hardly found at any Cambodian farm. Unstable quantity on the supply side has been one of the reasons behind the loss of production competitiveness to the neighboring countries including Vietnam and Thailand. The experience from the collaboration between Svay Rieng University with Svay Rieng Agricultural Cooperatives shows that vegetable producers are facing severe issues of waterlogging during the wet season causing their production to be least productive and delayed (Hong et al., 2021). Therefore, the introduction of the SD system is essential to study in determining its potential contribution to vegetable production during the rainy season which could also be essential for other vegetable producers across the country. The on-farm experiment was conducted with farmers in Svay Chrum District, Svay Rieng Province to solve the problem of unproductive soil due to high water content (saturation) by the installation of a subsurface drainage with plastic house and net house. Draining water from the production area under plastic houses and net houses would help farmers solve the problem of highly saturated soil and continue their production during the wet season. The system will be of great benefit to vegetable producers in terms of a production period that can be extended from intermittent to year-round. This will lead to a better market connection and production margin which is stable in income generation.

OBJECTIVE

The overall objective of the research is to determine the appropriateness, potential, and suitability of the subsurface drainage under different growing conditions with Chinese cabbage as per field application of vegetable producers in increasing the period and productivity during the rainy season.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted in Svay Chrum District, Svay Rieng Province, Cambodia (Fig. 1) with fifteen farmers' fields of vegetable producers who are members of Svay Rieng Agricultural Cooperatives (SAC). The experiment was carried out from August to November 2022. The soil characteristics of the experimental fields are located on the saturated soil of abandoned paddy fields with soil pH of around 5.5 of the loamy soil (averagely, clay: 17.5%, silt: 39.4%, and sand: 41.4%). The rainy seasonal precipitation ranges from 142.4 mm to 248.9 mm, while the temperature ranges from 27.9°C to 29.8°C, and the humidity ranges from 80% to 92.5% (Table 1).

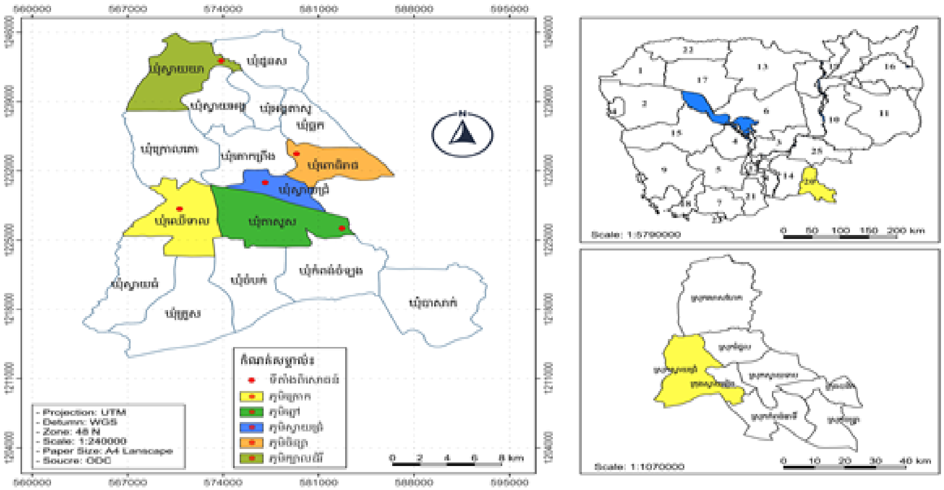

Fig. 1 The experimental location in Svay Chrum District, Svay Rieng, Cambodia

Table 1 Monthly rainfall, temperature and humidity during growing season in 2021-2022

Month	Rainfall (mm)		Temperature (°C)		Humidity (%)	
	2021	2022	2021	2022	2021	2022
Aug	218.8	174.3	30.0	29.4	91.0	87.5
Sept	255.5	238.5	29.3	29.8	96.0	85.0
Oct	254.2	248.9	28.8	27.9	92.5	92.5
Nov	248.4	142.4	29.0	29.0	86.0	85.0
Total	976.9	804.1	117.0	116.0	365.5	350.0

Experimental Design

The factorial design is used, containing fifteen farmers' fields with five replications and nine combined treatments including three SD systems and three GCs. The same design of the Subsurface drainage (SD) systems (SD1 = No Subsurface drainage pipe, SD2 = 2 rows Subsurface drainage pipe per bed, SD3 = 3 rows Subsurface drainage pipe per bed) were applied under the different Growing Conditions (GC) of open field (OP), net house (NH), and plastic house (PH). One farmer's field was used as one GC, and three SD systems were allocated. The pipes were sawed in a row at every 2 cm with 1/3 dept of pipe size to make holes for water inlets to drain through outlets to the nearby canal. The total land area for each farmer's field was 5 m x 15 m =75 m^2. The net house was fully covered by a 150-mesh net, and the plastic house was surrounded covered by a 150-mesh net with 300 UV plastic covering on top of the roof.

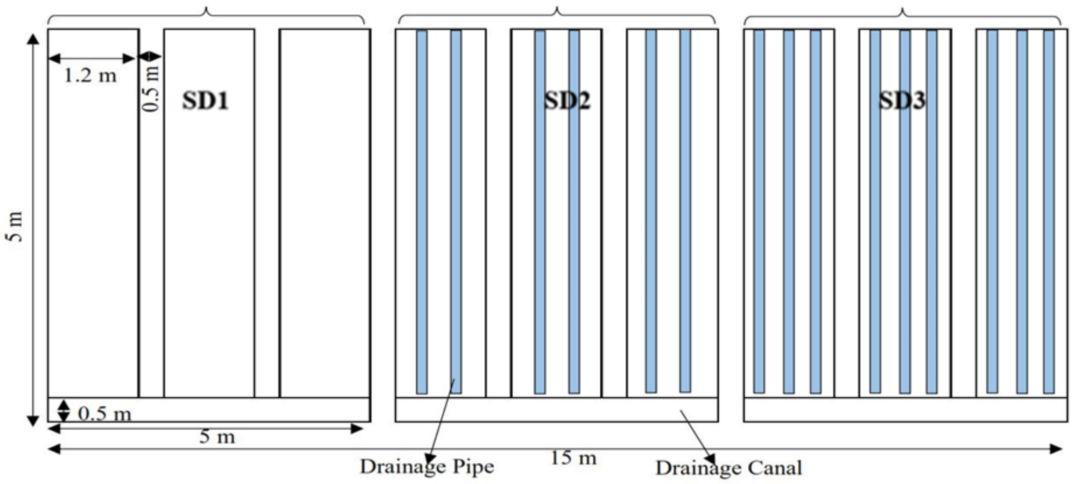

Fig. 2 Illustration of the experimental design for each farmer's field

Agronomic Practices

The Chinese cabbage seedlings were grown on the raised bed with the PVC pipe being buried underneath (sawed side goes to the ground) at a depth of 20 cm under the root zone. Mechanical methods were used for pest management. The weeding was controlled every week till the harvesting by hand. During the experiment, the diseases were not observed. The insects were normally bothered during the experiment, even in the net house or plastic house condition. The chemical methods of crop protection were used by spraying natural pesticides and by hand picking. For the irrigation, the plants were irrigated from pumped water sources by hand spraying with 20 liter-bucket. In case there was not enough or no rain, the water was applied at field capacity. Some agronomic traits such as root length, stem height, leaf area, and stem density (survived stem: is the total stem which is still alive both useful and useless stems at the harvesting date, useful stem: is the good stem which can be consumed, loss stem: is the died stem which cannot be survived at the harvesting day, damage stem: is the total of useless stems and died stems), and weight (estimated max yield: is the average weight of complete useful stems with 100% density at the harvesting date, useful yield: is the weight of good or consumable stems, loss yield: is the estimated weight of died stems which cannot be survived at the harvesting day, damage yield: is the estimated weight of useless and died stems) of the cabbages were collected. The collected data was analyzed as a factorial design using Statistix 8 program for the analysis of variance (ANOVA) and Minitab 20.4 for LSD mean comparison at p-value $p<0.01$, $p<0.05$. Before the analysis, the data were normalized to exclude the covariance being observed from the differentiation among farmer's plots.

RESULTS AND DISCUSSION

Effects on Agronomic Traits

To compare vegetative effects on the Chinese cabbage growth, the four key parameters were measured from the experiment including root length, stem height, leaf area, and leaf number. The result of the experiment is summarized in Tables 2-5.

Table 2 A root length change of Chinese cabbage

Treatment (Tr)	Root length (cm)		
	At planting day	At harvesting day	Increase
Growing condition (GC)			
Open field (OF)	2.43	9.39c	6.97c
Net house (NH)	2.51	10.14b	7.62b
Plastic house (PH)	2.42	11.30a	8.88a
Subsurface drainage (SD)			
SD1	2.47	8.99c	6.52c
SD2	2.45	10.21b	7.76b
SD3	2.43	11.63a	9.19a
CV (%)	6	18	18
Sig. (GC)	ns	**	**
Sig. (SD)	ns	**	**
Sig. (GC X SD)	ns	ns	ns

Table 3 Stem eight change of Chinese cabbage

Treatment (Tr)	Stem height (cm)				
	At planting day	At 1st week	At 2nd week	At harvesting day	Increase
Growing condition (GC)					
Open field (OF)	9.09	14.74 c	24.47c	26.44c	17.35c
Net house (NH)	9.13	14.89 bc	24.83bc	27.19b	18.07b
Plastic house (PH)	9.05	16.12 a	26.03a	30.09a	21.03a
Subsurface drainage (SD)					
SD1	9.17	13.59 c	24.00c	26.60c	17.44c
SD2	9.03	15.73 b	25.21b	27.83b	18.80b
SD3	9.07	16.41 a	26.13a	29.28a	20.21a
CV (%)	2	5	6	7	8
Sig. (GC)	ns	**	**	**	**
Sig. (SD)	ns	**	**	**	**
Sig. (GC X SD)	ns	ns	Ns	ns	ns

Table 4 Maximum leaf area change of Chinese cabbage

Treatment (Tr)	Maximum leaf area (cm^2/leaf)				
	At planting day	At 1st week	At 2nd week	At harvesting day	Increase
Growing condition (GC)					
Open field (OF)	8.90	28.54c	81.03c	187.25c	178.35c
Net house (NH)	8.98	30.10b	90.60b	196.87b	187.89b
Plastic house (PH)	9.03	34.82a	97.24a	206.43a	197.41a
Subsurface drainage (SD)					
SD1	8.88	29.03c	85.07c	189.20c	180.32c
SD2	9.04	31.81ab	90.91b	197.87b	188.84b
SD3	8.98	32.63a	92.88a	203.48a	194.50a
CV (%)	3	16	21	19	20
Sig. (GC)	ns	**	**	**	**
Sig. (SD)	ns	**	**	**	**
Sig. (GC X SD)	ns	ns	Ns	ns	ns

Tables 2 to 4 show that the level of changes for root length, stem height, and leaf area at the different growing stages of the Chinese cabbage are statistically different after the planting stages. Growing conditions and Subsurface drainage systems could make a significant impact on the growth of cabbage with a p-value less than 0.01. Overall, the level of increase of growing condition in Plastic House (PH) is observed to be better than Net House (NH) and Open Field (OF), while the level of increase of SD3 is observed to be better than SD2 and SD1. Plastic House (PH) performed the best as well as SD3, but the interaction of GC x SD was not significantly detected for root length, stem height, and leaf area of the cabbage in all growth stages.

Table 5 Leaf number change of Chinese cabbage

Growing conditions (GC)	Subsurface drainage (SD)	Number of leaves (leaf/stem)				
		At planting day	At 1st week	At 2nd week	At harvesting day	Increase
Open Field (OF)	SD1	2.99	3.63h	7.45e	10.06i	7.07i
	SD2	2.97	3.88g	8.59d	10.54h	7.57h
	SD3	2.97	3.91fg	8.40d	10.80g	7.83g
Net House (NH)	SD1	2.98	3.96ef	8.75d	11.25f	8.26f
	SD2	2.99	4.03cd	9.22c	12.55d	9.55d
	SD3	2.99	4.11ab	9.77ab	12.75c	9.77c
Plastic House (PH)	SD1	2.98	3.98de	9.16c	12.15e	9.18e
	SD2	2.97	4.10bc	9.69ab	12.96b	9.99b
	SD3	2.99	4.18a	10.07a	13.27a	10.28a
CV (%)		1	2	9	5	5
Sig. (GC)		ns	**	**	**	**
Sig. (SD)		ns	**	**	**	**
Sig. (GC X SD)		ns	**	*	**	**

The finding (Table 5) shows that leaf numbers were not significant at planting. At the later stage, the level of changes for the number of leaves at the different growing stages of the Chinese cabbage were statistically different. All parameters of growing conditions (GC) and Subsurface drainage (SD) systems could make a significant impact on the growth of cabbage with a p-value less than 0.01. In addition, the interaction of GC x SD was significant. Overall, the best performance of crop growth was observed under plastic house conditions with Subsurface drainage systems type 2 (SD2) and 3 (SD3).

Effects on Productivity

The Stem density, stem weight, and yield per hectare were measured and calculated from the experiment to compare productivity effects. The results from the experiment are provided in Tables 6 and 7.

Table 6 Stem density on the harvesting day of Chinese cabbage

Growing conditions (GC)	Subsurface drainage (SD)	Stem Density (stem/m^2)			
		Survived stem	Useful stem	Loss stem	Damage stem
Open field (OF)	SD1	9.57h	7.44g	15.43a	17.56a
	SD2	13.92g	8.16fg	11.08b	16.84ab
	SD3	14.92f	8.80f	10.08c	16.20b
Net house (NH)	SD1	17.78e	16.16e	7.22d	8.84c
	SD2	19.68d	17.86d	5.32e	7.14d
	SD3	20.68c	19.23c	4.32f	5.77e
Plastic house (PH)	SD1	20.09cd	18.29cd	4.91ef	6.71de
	SD2	22.00b	21.09b	3.00g	3.91f
	SD3	23.32a	22.36a	1.68h	2.64g
CV (%)		4	4	4	4
Sig. (GC)		ns	**	**	**
Sig. (SD)		ns	**	**	**
Sig. (GC X SD)		**	**	**	**

The result (Table 6) shows that the level of changes for the density of survived stem, useful stem, loss stem, and damaged stem on the harvesting day of the Chinese cabbage are statistically different. All parameters under growing conditions and Subsurface drainage systems could make a significant impact on the productivity of cabbage with a p-value less than 0.01. The interaction of GC x SD was significant. In overall, the plastic house condition with Subsurface drainage system type 3 was observed to be the best performance for survived stem and useful stem, while under plastic house condition with Subsurface drainage system type 2 and net house condition with Subsurface drainage system type 3 were observed to be better performance compared to Subsurface drainage system type 1 in all growing conditions. In addition, open field condition with Subsurface drainage system type 1 was observed to be the worst performance for loss stem and damage stem.

Table 7 Yield of Chinese cabbage

Growing conditions (GC)	Subsurface drainage (SD)	Total yield (ton/ha)			
		Estimated max yield	Useful yield	Loss yield	Damage yield
Open field (OF)	SD1	32.03i	9.53g	19.77a	22.50a
	SD2	32.42h	10.58fg	14.37b	21.84a
	SD3	32.90g	11.58f	13.27b	21.32a
Net house (NH)	SD1	33.36f	21.57e	9.63c	11.79b
	SD2	35.90e	25.65d	7.64d	10.25c
	SD3	36.92d	28.40c	6.38d	8.52d
Plastic house (PH)	SD1	36.49c	26.70d	7.17d	9.79cd
	SD2	37.90b	31.97b	4.55e	5.92e
	SD3	38.58a	34.51a	2.59f	4.07f
CV (%)		1	3	3	3
Sig. (GC)		**	**	**	**
Sig. (SD)		**	**	**	**
Sig. (GC X SD)		**	**	**	**

The result (Table 7) shows that the level of changes for the estimated maximum yield, useful yield, loss yield, and damage yield of the Chinese cabbage are statistically different. All parameters under growing conditions and Subsurface drainage systems could make a significant impact on the productivity of cabbage with a p-value less than 0.01. The interaction of GC x SD gradually developed and became significant. In overall, the plastic house condition with Subsurface drainage system type 3 was observed to be the best performance for estimated maximum yield and useful yield, while under plastic house condition with Subsurface drainage system type 2 and net house condition with Subsurface drainage system type 3 were observed to be better performance compared to Subsurface drainage system type 1 in all growing conditions. In addition, open field condition with Subsurface drainage system type 1 was observed to be the worst performance for loss yield and damage yield.

Discussion

The result of the experiment indicated high productive benefits for the Chinese cabbage in terms of yield at a rate of 15% and 22% for SD2 and SD3 systems respectively; and 58% and 66% for net house and plastic house conditions respectively. In comparison to the previous assignment conducted at the same location during the dry season, the increase is 26% to 34%, respectively (Hong et al., 2021). The yield from the experiment was slightly better than the one being conducted during the dry season at the Royal University of Agriculture with a yield of 28 tons/ha (Teb Kimheng, 2015). This would be more precise with the full-control condition of experimentation which would be possible in generalizing the actual condition of the country. In addition, a field experiment was conducted in paddy fields during the rainy seasons (October to May) from 2011 to 2015 to evaluate a suitable drainage system for improving the grain yield of lowland paddy soil. The saturated hydraulic conductivity of the soil in all treatments increased, which resulted in improved soil properties, water movement, and drain discharge rates (Mehdi et al., 2016). The results of the experiment were quite better in comparison to the installation of a subsurface drainage system resulting in an improvement of paddy yield by 13.27% and an increase in soil organic carbon content. However, it was the first year after the installation of the subsurface drainage; the yield could be expected to improve considerably during the succeeding seasons with appropriate and better cropping and irrigation management practices (Sahana et al., 2023). The increase was due to improvement in soil physical properties viz., infiltration rate, porosity, and chemical properties (low pH, EC, ESP) and improved nutrient availability in the drained field. Similarly, Abdel-Dayem, and Ritzema (1990) reported an increased yield of many crops to a tune of 10% for rice, 48% for berseem, 75% for maize, and more than 130% for wheat under a subsurface drainage system. The increase was because of decreased soil salinity, and improved air and water condition in crop root zones. The poor yield of maize in the undrained field due to poor soil physicochemical properties viz., shallow water table depth, high pH, EC, and ESP (Stieger and Feller, 1994; Samad et al., 2001 and Zhang et al., 2015), which limits the growth and development of crops in waterlogged saline-alkali soil (Arumugam et al., 2019). In addition, the enormous increase would result in reducing of water stress and strong drops of rain under the plastic house protection during the rainy season. This would bring enormous economic benefits for farmers. It is reported that the consumption of vegetables in Cambodia is approximately 1,062 million tons per year (SAAMBAT Project, 2020). This would translate into approximately contribution of 79,650-116,820 tons with the application of Subsurface drainage and approximately contribution of 307,980-350,460 tons with the application of growing condition (Net house and Plastic House) for the wet season production (June to December) for Cambodia with the application of the drainage under the net house or plastic house condition at the maximum scenario. There is still another concern regarding the cost of the drainage pipe and growing structures, which was included in the production. A more detailed analysis of the cost and benefit of the product will be included in future research assignments to make the drainage system and net or plastic house growing condition more determined and applicable for the rainy season.

CONCLUSION

The growth of the Chinese cabbage within the Subsurface drainage (SD2 and SD3) systems and growing conditions (NH and PH) performed better under both saturated and drought conditions. At the time of rain, the cabbage could continue its growth with less effect, while during the time of drought, cabbage could maintain its yield, possibly because of good aeration of the soil and less soil compaction after a strong drop of rain. The analysis still excluded the cost-effectiveness and efficiency of the experiment due to the absence of detailed expenditures on drainage pipe, construction of the net and plastic house, and water consumption is also excluded. Anyway, future research should be conducting a detailed analysis of the loss of other nutrients in soils, water consumption, and possible economic loss as a result of drainage systems and conduct a detailed analysis of the economic benefits of drainage systems with actual price estimation.

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