Assessing the status of mechanization and proposing technical solutions for lime farming in the Mekong River Delta

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ABSTRACT

This study was conducted to assess the current status of mechanization in lime growing activities of farmer households in the Mekong River Delta. The current status of mechanization was assessed through different groups of criteria that reflect the scale of mechanization level, resources of farmers applying mechanization, results, and production efficiency. The level of machine and technology application was assessed by building the mechanization index. With a sample of 555 lime farmer households in Long An and Ben Tre, the results showed that the application of machines and equipment in lime growing activities in the study area was quite limited. Households mainly used machines in two stages including land preparation (42% of households applying mechanization) and tree care (93%). The growth rate and mechanization investment of the 2016-2019 period were almost unchanged. The estimated results of mechanization index showed that most of lime growers had a very low mechanization application level with an average value of only 0.09. In fact, 2% of the surveyed households do not invest in mechanization in lime production, 89.8% are in the group with very low mechanization level, 3.1% at low mechanization level, only 5.1% at medium mechanization level and no household had high mechanization application level. From the survey results, potential technical solutions for lime farming in the Mekong River Delta were also proposed, including mechanization for small and medium farms and mechanization considerations for plant care. Finally, in order to improve the quality of lime fruit, the semi-mechanization harvesting systems and appropriate storage facility and suitable packaging are highly recommended.

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1. Introduction

In recent years, lime tree planting activities in the Mekong River Delta have achieved good results and efficiency, bringing income to lime farmers. Especially, limes grown under VietGAP model with good appearance, uniform size, and without pesticide residue are exported. In Long

An, lime export value is always over 30% of the total fruit export turnover of the province. Recently, many households growing limes can earn a profit of 30 - 40 million VND per 1,000 m^2. In the Mekong River Delta, lime trees are grown in Long An and Ben Tre while they are also planted in small areas of some other provinces in the region. Over the years from 2015 to 2019, the lime production area in Long An increased sharply from 6,734.01 ha to 10,825.72 ha. Meanwhile, the planting area of lime in Ben Tre tended to increase from 2015 to 2018 and then has decreased slightly after 2019 (a decrease of 91 ha).

Along with the development of lime growing activities is the promotion of mechanization application in agricultural production according to the Government's orientation. Vietnam's agricultural sector has set a target of a level of 80% - 100% mechanization at stages in agricultural production and of 5 - 6 HP/ha for the average capacity of machinery and equipment nationwide by 2030. In producing areas of agricultural commodities, the level of mechanization is synchronized and automated (Ngoc, 2020). The benefits of applying mechanization and high technology in agricultural production have been studied and confirmed by many authors. According to Bello (2013), agricultural mechanization helps to increase labor productivity, increase production efficiency per unit area, and reduce production costs of manual labor or animals. Singh & Singh (1972) concluded that farms with tractors yielded higher yields of wheat, rice, and sugar cane than farms without tractors. Similarly, Nandal (1986) stated that farms with tractors produced higher yields of wheat and rice, used more production inputs, and managed better uptime. Balishter & Singh (1991) studied farm yields at three different levels of mechanization. The results showed that fully mechanized farms had 10 - 27% higher yields, partially mechanized farms had 2 - 26% higher yields than completely non-mechanized. In addition to the above benefits, agricultural mechanization also created indirect jobs for people involved in the operation, repair, and maintenance of machinery and equipment (Verma, 2006).

However, in the agricultural sector in the Mekong River Delta, the application of high technology in production, processing and preservation remains limited. Sustainable production models, that adapt to climate change, also do not have enough technical and market basis, as well as strong motivation and support to replicate the model. According to the Department of Science, Technology and Environment (Ministry of Agriculture and Rural Development), climate change and sea level rise in the Mekong River Delta are happening faster than the forecast (Thanh, 2019). The effects of sea level rise (SLR) on flooding and drainage in the lowlands of the Mekong River Delta are becoming increasingly apparent. In 2008 and 2009, due to the double impact of SLR and high tide, Kien Giang, Bac Lieu and Can Tho were heavily flooded. Even upland areas such as urban areas, residential areas and roads in some areas have been flooded. According to the Institute of Hydrometeorology, Hydrology and Environment - Imhen (2010), by 2050, the flooded area may have been up to 3,514,403 ha, accounting for about 89% of the whole area of the Mekong River Delta (natural land in the Mekong River Delta is about 3,936,000 ha), about 20% increase compared to the historic flood in 2000. In the context of climate change impacts, the promotion of mechanization brings direct benefits such as increasing productivity and profitability and also brings indirect benefits in contributing to climate change adaptation and mitigation.

According to Sims & Kienzle (2017), farmers, especially smallholders, always had to depend on a temperate climate for farming and food security. Today, due to widespread extreme and erratic weather and the effects of climate change increasing its frequency, small agricultural production systems are becoming more and more insecure. Therefore, Sims & Kienzle (2017) emphasized the role of mechanization to build a climate resilient agriculture that meets three factors including (1) increase productivity to provide food security; (2) adaptation to extreme weather events and long-term weather events affecting agriculture and food security; and (3) mitigate the effects of climate change through GHG (Greenhouse gas) emission reduction. Capaz et al. (2013) reported that the use of machinery in sugar cane harvest would help reduce 39.3% of GHG emissions in Brazil. Ennin et al. (2014) also demonstrated that applying mechanization during soil preparation and fertilization yielded higher yields than farmers' traditional practices in Ghana. Also, mechanization combined with a reduction in the use of piles will significantly reduce the impact of sweet potato production on deforestation and climate change.

In the above context, the objectives of this study were (1) analyzing the current situation and level of mechanization in lime growing activities in the Mekong River Delta, and (2) evaluating the mechanization level and the effectiveness of mechanization in climate change adaptation. The study results provided a general and comprehensive perspective on the development of high-tech agriculture in lime production, from which solutions can be proposed to improve the efficiency of machine application, and promote mechanization in lime production activities in the Mekong River Delta.

2. Materials and Methods

2.1. The concept of machinery and equipment

According to Circular 17/2019/TT-BKHCN of the MOST (2019), machinery and equipment are a complete structure, including details, detail assemblies and parts that are linked together to operate and move according to the intended use.

2.2. The concept of agricultural mechanization

According to Clarke (1997), agricultural mechanization is the process of improving the labor productivity of the farm through the use of agricultural machines and tools, from simple hand tools to high technology machines. Clarke (1997) identified agricultural mechanization as the application of tools, machinery as inputs for agricultural production. There are three resources used including human labor, draft cattle and agricultural machinery and they can be complementary in the production process. Starkey (1998) defined agricultural mechanization as the development of machinery and equipment applied in agricultural production to improve the efficiency of human labor, promptly respond to the seasons. According to Nguyen (2018), agricultural mechanization is the synchronous implementation of infrastructure, machinery, equipment and investment conditions suitable to the scale and production level of each region; above all, they are the large-scale concentrated commodity production areas and the heavy production stages.

Thus, mechanization in agricultural production is the process of using machines, tools and tools to partially or fully replace the force from humans or animals. Moreover, agricultural mechanization contributes to improve the efficient use of input factors such as increasing labor productivity, land productivity, and reducing production costs, resulting in improving income through increasing productivity and increasing production scale. Therefore, agricultural mechanization is also a prerequisite for large-scale production by expanding cultivated area (Bello, 2013).

2.3. Method of evaluating the degree of mechanization application

2.3.1. Evaluation of the status of mechanization application in production

To assess the status of mechanization application in agricultural production in farming households, this study applied the criteria system designed by Nguyen (2018) which was divided into different groups of indicators as follows: the group of indicators reflecting the scale and level of mechanization; group of indicators reflecting the growth of mechanization; the group of indicators reflecting the resources of farming households applying mechanization; and group of indicators reflecting production results and efficiency.

2.3.2. Evaluation of the degree of mechanization application in production

In previous studies, to quantify and classify the degree of mechanization application, the authors often applied a classification based on a mechanization index such as the mechanization level index in planting (Rasouli & Ranjbar, 2008) or the mechanization index reported by Nowacki (1978) and Minli et al. (2017). From the fluctuation of these indicators, it can be seen that the level of mechanization should be established for each study area. According to Nowacki's (1978) approach, the mechanization index is the ratio of machine energy (including fuel energy and machine energy) to the sum of the machine, human, and animal energy. The higher the mechanization index, the more work is done by machine.

To assess the level of mechanization application in lime production in the Mekong River Delta, in addition to statistical criteria such as the number of machines, types of machines, the cost of investment in machinery and equipment, this study estimated the Mechanization Index (MI) for lime growers. The MI index calculation was the basis to evaluate how high the level of application of mechanization of each farmer household was, as well as help to compare it among different regions accurately and objectively. This study applied the mechanization index calculation formula including the cost factor of Singh (2006):

$$MI_{ij} = \frac{C_{MI_{ij}}}{C_{MI_{ij}} + C_{H_{ij}} + C_{A_{ij}}}$$

In which:

MI_{ij}: mechanization index of product i in household j;

CM_{ij}: the cost of using the machine of product i in household j;

CH_{ij}: labor cost of product i in household j;

CA_{ij}: cost of using the animal power of product i in household j.

2.3.3. Evaluation of the effectiveness of mechanization in climate change adaptation

To evaluate the effectiveness of the application of mechanization and technology in the context of climate change adaptation, the study was based on two assumptions that: (1) the higher level of mechanization applied by households, the higher financial efficiency is achieved; and (2) under the same conditions affected by climate change, households that apply mechanization and technology will achieve higher financial efficiency than households that do not apply mechanization. To test the above assumptions, the study applied the One-way ANOVA test to evaluate the difference among groups of households with different levels of mechanization application. The groups used in the analysis are distinguished as presented in Table 1.

The financial ratios used in this study included revenue, cost, profit, ratio of revenue/cost, rate of profit/cost, rate of profit/revenue. These financial ratios have also been applied by some previous studies to evaluate production efficiency (Nguyen, 2009; Duong & Nguyen, 2014).

2.3.4. Data collection

Secondary data related to the current situation of mechanization and technology application for the Mekong River Delta were collected through reports and statistics from Department of Agriculture and Rural Development and Statistical Offices of the provinces. Primary data in the study were collected through direct interviews with 555 lime growers in Ben Tre and Long An. These are the two provinces with the largest lime production areas in the Mekong River Delta, of which Long An has 9,165 ha, and Ben Tre has 2,300 ha of lime trees (BTSO, 2019; LASO, 2019). In Long An province, Ben Luc and Duc Hue districts are the two typical districts with the largest area of lime cultivation in the region (6,644.75 and 2,629.80 ha, respectively). As for Ben Tre province, Lime is grown prominently in Giong Trom district with 1,966 ha. All collected data were analysed using Microsoft Excel version 16.27 and IBM SPSS software version 25.

3. Results and Discussion

3.1. Assessing the status of mechanization application at lime farming households

3.1.1. Scale and level of mechanization

Most of the stages in the lime planting activity had a very low level of mechanization, the households mainly use machinery in the two stages of land preparation (42% of households applying mechanization) and take care of trees (93%). There were no households using machinery and equipment in the planting and harvesting stages. The results showed that transportation (26%) and the stage of storage and preservation (4%) were used by the households (Figure 1). For lime trees, the application of mechanization is recognized mainly in two stages: soil preparation and tree care. Specifically, to prepare the soil for planting, machines such as cultivators and Kobe excavators are used by farmers. In the tree-care stage, the households have invested in spraying machines, pumps, and weeding to support farming activities, such as discharging water with pumps during the rainy season (water will damage the lime tree without draining).

One feature of the application of mechanization in lime cultivation is that households rent machines or use mechanized services, or invest in the machines themselves. According to the survey results, farmers often rent machinery, or use mechanized services during the land preparation stage, or invest in machinery and equipment themselves during the tree care stage. The cost of hiring a land preparation service varies according to the production area and the type of machine hired. For example, the renting cost of the Kobe excavator is about 2.5 million VND per ha; whereas

Table 1. Classification of different households groups with different levels of mechanization application

Object	Group	Explanation
Households	No mechanization	No mechanization application, MI = 0
	Very low mechanization	$0 < MI \leq 0.25$
	Low mechanization	$0.25 < MI \leq 0.5$
	Medium mechanization	$0.5 < MI \leq 0.75$
	High mechanization	$0.75 < MI$
	Affected by climate change	Households report they are affected by climate change
	Not affected by climate change	Households report they are not affected by climate change

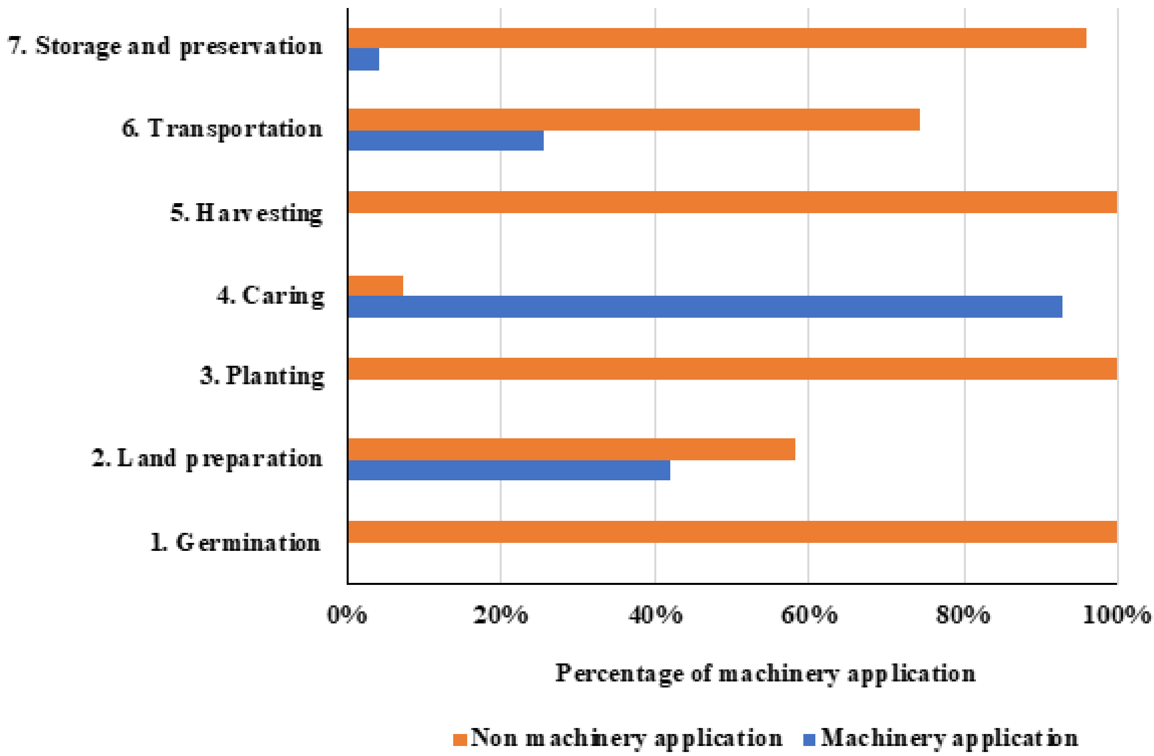

Figure 1. Rate of machinery application in lime growing.

the cost is about 16 million VND per ha for multi-purpose cultivators (50 horsepower, HP). Most of the cultivators are Yanmar brand. The investing cost of machinery during the tree-care stage of lime farmers varies depending on the brands and capacity of machines. On average, the spraying machine is from 4 - 4.5 million, the water pump is from 1 - 8 million depending on the type, the lawn machine is from 6.6 - 8 million.

In Long An, the use of a mist sprayer (airplane, smoke spraying in the wind direction) was tested, but it was ineffective partly due to the design of the machine's operation mechanism. It is due to the characteristics of the lime tree, including large leaf foliage, pests from tree trunks and roots. The stages of planting and harvesting are mainly done by hand. However, it should be noted that the above machines do not completely replace manual labor in the respective stages, only help the lime planting activity shift from full manual labor to the level of mechanization in part and machines. In addition, equipment applied are not completely automated, they are mainly operated by human beings.

The status of mechanization application between the two areas studied also shows noticeable

Table 2. Comparison of mechanization rate between Ben Tre and Long An

		Provinces	
		Ben Tre	Long An
Germinating	Machinery application	0.0%	0.0%
	No machinery	100.0%	100.0%
Land preparation	Machinery application	1.9%	88.9%
	No machinery	98.1%	11.1%
Planting	Machinery application	0.0%	0.0%
	No machinery	100.0%	100.0%
Caring	Machinery application	86.8%	100.0%
	No machinery	13.2%	0.0%
Harvesting	Machinery application	0.0%	0.0%
	No machinery	100.0%	100.0%
Transport	Machinery application	15.1%	37.8%
	No machinery	84.9%	62.2%
Harvesting	Machinery application	0.0%	0.0%
	No machinery	100.0%	100.0%
Storage and preservation	Machinery application	0.0%	8.9%
	No machinery	100.0%	91.1%

differences (Table 2). The general results show that lime growing households in Long An had a higher rate of mechanization than that in Ben Tre (33.7% versus 14.8%). In all production stages, Long An province always has a higher rate of mechanization. The most obvious difference is in the land preparation stage because 88.9% of the households in Long An have used land preparation service, while in Ben Tre only 1.9% of those have used the service, the rest prepare the land with manual labor.

3.1.2. Agricultural mechanization growth

Regarding the agricultural mechanization growth rate over the years, most of the machinery was invested by households before 2016, so the rate of mechanization in the 2016 - 2019 period remained generally unchanged. The reason for the low growth rate in mechanization application can be explained by several reasons. First, the machines being invested by farmers such as pumps, lawn mowers and sprayers were devices of which the structure and design were not too complicated, with a quite long service life (from 5 to 10 years). As such, after the initial investment, farmers could use it for many years. In addition, over 40% of surveyed households said that repairing and maintaining machinery is relatively simple, the repair cost is relatively low. As such, they do not need to invest and/or buy replacement equipment.

Second, about 94% of the households said that they have not received support for the cost of purchasing production support machines and 77% have not undergone training in using machinery and equipment in lime production. According to the survey, most farmers do not have access to new production techniques and technologies, but still produce from traditional experiences. Thus, they do not require equipment in production technology lines or modern farming techniques. About 68% of the farmers said that they do not need to invest in applying additional machinery in the future.

3.1.3. Group of indicators reflecting the resources of households applying agricultural mechanization

A comparison of the resources of lime farmers between the two surveyed areas shows a difference. It is noticeable that the lime planting area and the average value of the machines invested in Long An are significantly higher than those in Ben Tre (Table 3). This figure accurately reflects the real situation. In Long An in 2019, the lime planting area is 10,826 ha, reaching 103% of the plan, as much as 118% compared to 2018; the area of fruiting lime trees is 8,913.4 ha. Lime trees are mainly grown in Ben Luc district (5,393.3 ha), Duc Hue (2,612 ha). In Ben Tre, lime trees are mainly grown in Giong Trom district (2,022 ha). In districts like Cho Lach, Chau Thanh, Ba Tri,

Table 3. Comparison of lime production resources between Ben Tre and Long An

			Provinces	
			Ben Tre	Long An
Education level	Mean		8[a]	10[b]
Total household members	Mean		4[a]	4[a]
Number of lime growers	Mean		2[a]	2[a]
Number of laborers who know how to use machines	Mean		2[a]	2[a]
Number of laborers who receive training in machinery	Mean		0[a]	1[b]
Number of years growing lime/grapefruit	Mean		18.9[a]	10.3[b]
Specialized in lime cultivation	No	Column N%	26.4%	15.6%
	Yes	Column N%	73.6%	84.4%
Lime - Crops	No	Column N%	81.1%	97.8%
	Yes	Column N%	18.9%	2.2%
Lime planting area	Mean		0.4218[a]	2.1794[b]
Average machine value	Mean		0.51[a]	2.09[b]

Values in the same row and subtable not sharing the same subscript are significantly different at $P < 0$ .05 in the two-sided test of equality for column means. Cells with no subscript are not included in the test. Tests assume equal variances.[1]
[1]Tests are adjusted for all pairwise comparisons within a row of each innermost subtable using the Bonferroni correction.

Binh Dai, they are only planted with an area of less than 100 ha. The average size of lime orchards of households in Long An is four times larger than that of households in Ben Tre (2.09 ha compared to 0.51 ha). As a result, it can be seen that Long An lime growers spend much more money on production mechanization than in Ben Tre.

3.1.4. Results and production efficiency of household applying mechanization

Regarding the results and efficiency of growing lime (Table 4), Long An province showed better results than Ben Tre. Thanks to the advantages of large scale and high investment costs, the results from lime production of farmers in Long An were significantly higher and different from those in Ben Tre, which were statistically significant in all terms of output, revenue, total cost, and profit (Table 3). Good business results and high profits can be seen as a premise for farmers to continue to reinvest in lime planting, expand the scale and increase investment in machinery and equipment.

For 2019, the estimated total output of lime harvested in Long An province reached 156,126 tons. The price of limes with seeds ranged from 4,000 - 15,000 VND/kg, fell 3,000-10,000 VND/kg over the same period; seedless limes ranged from 10,000 - 20,000 VND/kg, fell 5,000 - 10,000 VND/kg. Farmers had a profit of 70-150 million VND/ha/year. In Ben Luc district of Long An province, the seedless lime tree has become the staple crop of the locality after being piloted by farmers since 2002. Since 2011, the exclusive brand name Ben Luc lime has been built. By 2014, Ben Luc district officially established Thanh Hoa Agricultural Service Cooperative, opening a new direction for Ben Luc lime trees, developing the area scale of seedless lime, building a specialized farming area, orientating the development of production model according to VietGap and GlobalGap standards. The consumption market for limes in the district is quite diverse, such as domestic consumption and export through official channels, through unofficial channels, exported to European markets, Middle East countries and regional countries.

Table 4. Results of lime production of households in Ben Tre and Long An

	Provinces	
	Ben Tre	Long An
Yield of 2019	2.68[a]	49.90[b]
Revenue from cultivation	142.58[a]	535.67[b]
Total cost of growing lime	30.62[a]	147.45[b]
Profits from growing limes	101.67[a]	380.03[b]
Revenue/Cost	3.83[a]	5.60[a]
Profit/Cost	2.83[a]	4.60[a]
Profit/Revenue	0.23[a]	0.48[a]

Values in the same row and subtable not sharing the same subscript are significantly different at $P < 0.05$ in the two-sided test of equality for column means.

Table 5. Comparison of mechanization index between Ben Tre and Long An

		Provinces	
		Ben Tre	Long An
Mechanization index of farm households (in groups)	No mechanization	3.8%	0.0%
	Very low mechanization	94.3%	84.4%
	Low mechanization	0.0%	6.7%
	Medium mechanization	1.9%	8.9%
	High mechanization	0.0%	0.0%

In contrast, in Ben Tre, lime is not the most prominent crop among citrus trees. Regarding citrus fruit trees, the most planted trees were grapefruit (8,824 ha), lime (2,300 ha), oranges and tangerines (1,980 ha). In addition, the province also has other prominent fruit trees such as rambutan (5,5330 ha), longan (2,455 ha), durian (2,216 ha), and mangosteen (1,230 ha) (BTSO, 2019). Therefore, the scale, level of investment, intensive farming and production efficiency were lower than those in Long An province.

3.2. Estimating the mechanization index of farming households

The estimated results of mechanization index show that most of the lime growers had very low levels of mechanization application. The mechanization index of the surveyed households ranged from 0 to 0.60, of which the average value was only 0.09. More specifically, 2% of the surveyed households did not invest in mechanization in lime production, 89.8% were in the group with very low mechanization, 3.1% at low mechanization, only 5.1% at medium mechanization level and no household had high level of mechanization application (Figure 2).

The reality of applying mechanization in lime production tends to depend more on the scale of agricultural production than on the resources of the application. Specifically, households, that do not apply mechanization, have 23 years' experience in growing grapefruit. There is only one person in the household participating in growing lime. While households with higher mechanization level have experience in lime production less than 15 years, the number of people involved in lime production per household is 2. The scale of agricultural production in general and lime cultivation in particular increased in the same direction with the application of machinery in production.

Non-mechanization households only have about 0.21 ha of agricultural land, of which 0.125 ha is used for growing limes; while households with very low and low MI indexes have a total agricultural land area of about 1.46-1.48 ha, of which about 1.22-1.46 ha is for lime trees; the medium mechanization households have about 1.92 ha of agricultural land/household, of which about 1.66 ha is for growing limes. Lime production in 2019 also increased corresponding to the levels of the MI index (1.5 tons in non-mechanization households, 16.96 tons in households with very low MI, 19.33 tons in households with low MI, and 166.8 tons in households with medium MI).

The correlation between the scale of agricultural production and the degree of application of machinery in production was again shown through the distribution of the MI index by two provinces (Table 5). In which, households who did not use machines to grow limes were completely distributed in Ben Tre and 94.3% of surveyed households in Ben Tre had very low mechanization. In Long An province, although the majority of lime growers were also very low mechanization (84.4%), there was an additional distribution of households with low MI (6.7%) and medium (8.9%).

3.3. Evaluation of the effectiveness of mechanization in climate change adaptation

For the total number of surveyed households, only 2% of households reflect that they were not affected by climate change at all. Therefore, to evaluate the effectiveness of the application of machines in climate change adaptation, this study examined financial efficiency indicators within groups of households affected by climate change and groups at different levels of mechanization (Table 6). The statistical results indicated that there was non-significant difference in groups with different levels of mechanization af-

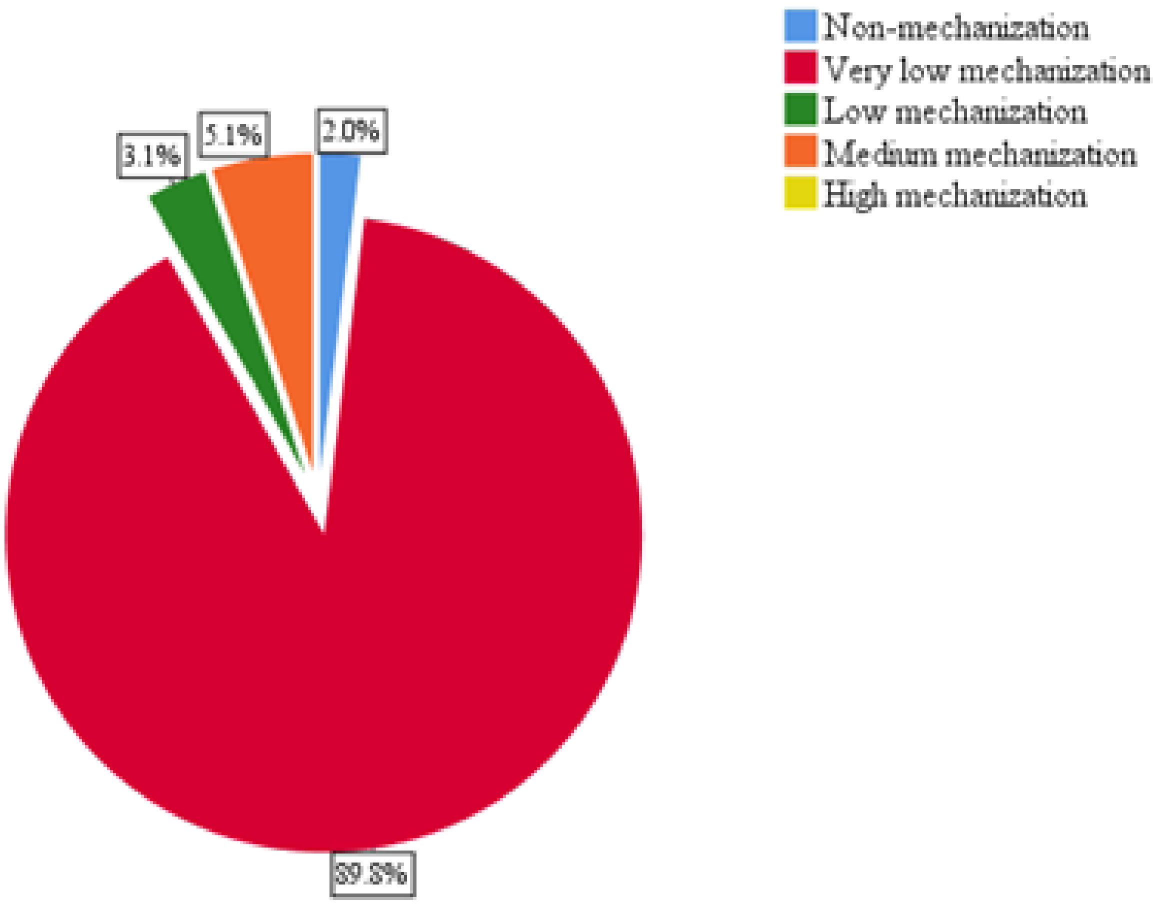

Figure 2. Mechanization index distribution of lime growing households.

Table 6. Results of ANOVA test

	Sum of Squares	df	Mean	Square	F	Sig.
	Between Groups	1234717.073	3	411572.358	1.474	0.221
Revenue from cultivation	Within Groups	128728995.119	461	279238.601		
	Total	129963712.192	464			
	Between Groups	58173.027	3	19391.009	1.399	0.243
Total cost of growing lime	Within Groups	6391571.986	461	13864.581		
	Total	6449745.013	464			
	Between Groups	283.008	3	94.336	1.141	0.332
Revenue/Cost	Within Groups	38119.311	461	82.688		
	Total	38402.319	464			
	Between Groups	283.008	3	94.336	1.141	0.332
Profit/Cost	Within Groups	38119.311	461	82.688		
	Total	38402.319	464			
	Between Groups	6.248	3	2.083	4.133	0.007
Profit/Revenue	Within Groups	232.282	461	0.504		
	Total	238.530	464			

fected by climate change in terms of production efficiency, except for the rate of profit/revenue. Thus, it is impossible to confirm that the application of machinery in production really helps

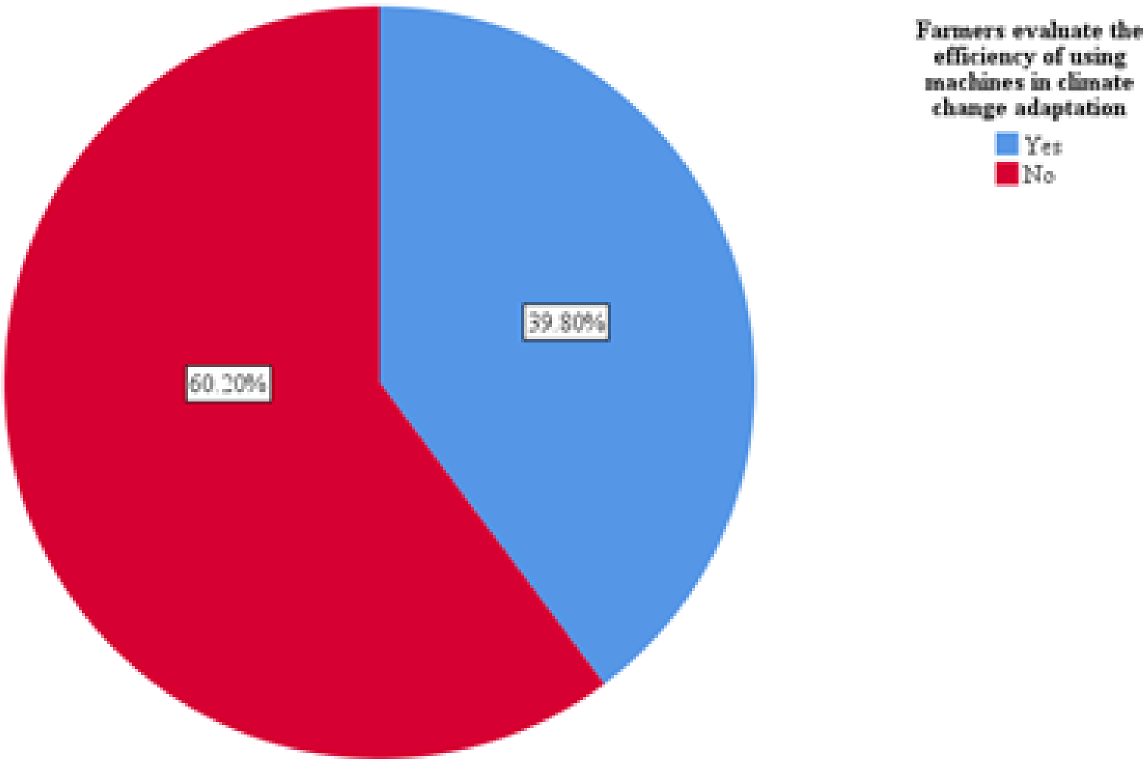

Figure 3. Farmers evaluate the efficiency of using machines in climate change adaptation.

farmers to adapt to climate change.

The negative effects of weather and production conditions that farmers reflected the most are drought, lack of water (68.4%), aluminum contamination (61.2%), and increased disease (43.9%). Although the proportion of households thinks that they are affected by climate change on agricultural production, the majority of farmers self-assess that the use of machinery and equipment is not helpful for climate change adaptation (Figure 3). This assessment is mainly because the machines used at the present are mostly simple ones, supporting and reducing manual labor, the investment in complete machine systems under a certain high-tech model is very little. This result is similar to the reviews by Nguyen et al. (2017).

4. Improvements for the lime production in the Mekong River Delta

The current analyses showed that the mechanization in lime production in the Mekong River Delta is very limited and lacks synchronization. However, the findings also demonstrate that the lime industry is highly potential in large scale production. In this part, the prospects of improvements for the lime production in the Mekong River Delta need to be discussed.

4.1. Mechanization for small and medium farms

The big size of agricultural machines does not always bring benefits. The large machine is more viable when working in large land areas. According to Blackmore et al. (2008), two constraints for applying mechanization of small farms are the unsuitable condition for large machine operation and the too much capital investment for the big machine. The lime farms in the Mekong River Delta area are characterized with small and medium scales (from 0.5 to 2 acres) and thus considerations need to be taken when improving the mechanization. One of the main benefits of mechanization using a big machine is to reduce the labor cost in the labor-shortage areas (Schmitz & Moss, 2015). The Mekong River Delta area has not encountered a lack of labor, and thus the large-scale machines focusing on reducing the labor costs seem not to be very effective. The mechanization in lime production in the Mekong River

Delta is currently far behind the expectation but the feasibility of improvement should focus on the small and smart machine that suitable for small and medium farms.

4.2. Mechanization considerations for plant care

4.2.1. Irrigation and fertilizing using an open hydroponic system (OHS)

The effectiveness of lime production relies much on plant care techniques where the application of novel technology and mechanization become competitive advantages. The advanced techniques in plant care of lime orchards involve in the efficiency of irrigation and nutrient management. The lime growers in the Mekong River Delta may be very experienced in the field but need to be updated with the latest technology to improve productivity. One of the advanced technologies is the open hydroponic system. The OHS (open hydroponic system) has been successfully applied in many crops such as citrus, avocados, peaches, almonds, grapes (Morgan & Kadyampakemi, 2012). The OHS brings many benefits for lime production such as maximize the efficiency of water and nutrient uses, accurately deliver nutrients to improve its availability, modulate roots in the expected zone and reduce nutrient leaching (Morgan & Kadyampakemi, 2012). Though it has not been investigated in lime production yet, the OHS has been reported to be highly suitable for citrus production. Regarding the horticulture practice, the OHS increased the citrus yield by over 20% that has been widely reported (Morgan et al., 2009; Prazeres et al., 2017; Ferrarezi et al., 2020). In particular, five-year observation of using the OHS in the citrus orchards infected by Huanglongbing (HLB) disease showed that the system is suitable for application with higher tree density even under the common disease condition (Ferrarezi et al., 2020). The OHS system has been also documented to be more economical for capital investment. The analysis using net present value (NPV) to evaluate the cost and benefits of OHS demonstrated that within 5 to 7 years of the investment, the OHS will return the positive profits (Roka et al., 2009). The timeframe for the return of investment is considered to be appropriate for the lime production practice in the Mekong River Delta area since many farmers are experienced with more than 10 years involving in growing lime.

The OHS can boost the sustainability of lime production in the era of climate change. The OHS greatly contributes to the sustainability of water use by controlling wastewater treatment using for irrigation and fertilization. Prazeres et al. (2017) proved that the hydroponic system is very promising for wastewater treatment in agriculture of food production. Consequently, the wastewater can be efficiently reused and thus the contamination of surface water and groundwater can be minimized. The main outcome of the system is to minimize the water shortage that may cause shortly. Yet, soil salinity has not affected the lime orchards in the current surveying, the problem would be exacerbated soon since other proximate areas have been experienced with a serious salinity.

4.2.2. Accurate spraying

Another consideration for the application of technology and mechanization for lime production is the pesticide spraying step. The current farming practices in lime production in the Mekong River Delta heavily rely on manual spraying. This practice has been considered as non-uniform, excessive spraying and may cause a reduction in crop yield. The inaccurate also may cause the contamination of soil by the excessive pesticide dripping from the trees (Desale et al., 2019). Farmers' safety issues would also be another consideration when applying the manual spraying (Faiçal et al., 2017) due to the direct contact with those chemical contain. The unmanned aerial vehicle (UAV) has been proposed as an effective option for the lime orchards in preventing the disease. The concept of using the air-assisted sprayer for precision citrus was introduced by Khot et al. (2012). By using the proposed system, the pesticide usage was reduced by 50% whereas the spray deposition was maintained as unchanged. In another study, the cost of applying UAV for accurate spraying of citrus has been analyzed. The effectiveness of the UAV in disease prevention was successfully maintained. The cost of applying UAV was comparable to conventional spraying (Martinez-Guanter et al., 2020). From the aforementioned analyses, it is recommended that UAV would be an appropriate choice for mechanization of lime production focusing on plant care stage.

4.3. Semi-mechanized harvesting

Improving the harvesting practice in lime production is necessary to increase productivity and reduce the labor cost. Many efforts have been made to apply the mechanization in citrus production. Though the mechanical shaking can reduce labor cost and over 90% of fruits can be harvested in a short period (Arenas-Arenas et al., 2017), tree damaging is inevitable that lead to undermining the next crop (Pu et al., 2018). The mechanical vibration for harvesting is also incapable of small and medium lime orchards in the Mekong River Delta. The manual harvesting seems to be suitable for current practice in lime production. However, the improvement focuses on reducing the cost is necessary. The manual labor cost comprises of over 44% of citrus production costs (Costa & Camarotto, 2012). The cost analysis in the current survey in lime production at the Mekong River Delta also suggests that labor cost was the major for the harvesting step. Under this scenario, the semi-mechanized harvesting would be the most appropriate and be recommended. The semi-mechanized harvesting system proposed by Costa & Camarotto (2012) includes four platforms vertically moving along the tree height: from bottom to the highest top to harvest fruits. The fruits were then conveyed and boxed in the same system. The productivity of harvesting using semi-mechanized systems increased by 40%. The increase in productivity of the machine aid system has been also reported in another study of Ferreira et al. (2018). The findings also suggested that the semi-mechanization harvesting systems can also improve the ergonomic of the fruit pickers and reduce the physical stress during harvesting (Costa & Camarotto, 2012; Ferreira et al., 2018). The mobile platform of harvesting thus may be most appropriate for the mechanization of the lime production in the Mekong River Delta.

4.4. Storage

Lime fruit is most commonly marketed in a fresh form that needs an appropriate storage facility and suitable packaging. Unfortunately, most of the lime growers in the Mekong River Delta lack of cold storage facility that leads to stress to be sold before the fruit becomes perishable. The sale price much depends on the season and reaches a peak around February. From December to February the market price can increase by approximately 70% (Ho, 2016). The big lime grower thus can invest a cold storage facility to maintain sustainability in lime production by stabilizing the sale price over a certain period (e.g. two months). Research has proved that lime quality can be extent the shelf-life from 45 to 60 days by cold storage and under certain treatment conditions (MohammadrRezakhani & Pakkish, 2017; Opio et al., 2017; Yousefi et al., 2019). Yet, the cold storage facility may not be applicable for small scale lime production, the medium and big growers are recommended to invest the facility to get the production competitive advantages. The high-quality fruits do not only serve for the freshly-consumed market but also the potential processing industry.

5. Conclusions

The results show that the status of application of machines and equipment in lime growing activities in the survey areas was not really high. Households mainly used machinery in two stages of land preparation (42% households applying mechanization) and tree care (93%). The current situation of mechanization application between the two areas also shows certain differences. The general results showed that lime growing households in Long An had a higher percentage of mechanization than in Ben Tre (33.7% versus 14.8%). In all production stages, Long An province always has a higher rate of mechanization. It is noticeable that the lime growing area and the average value of the machines invested in Long An are significantly higher than those in Ben Tre. The resources of education level and degree of lime specialized cultivation also differ between the two regions. These characteristics lead to better production results and higher efficiency in Long An than in Ben Tre. In addition, the estimated results of mechanization index show that most of the lime growers have very low levels of mechanization application. Regarding the efficiency of the application of machines to cope with climate change, there was statistically insignificant difference in production efficiency. Thus, it is impossible to confirm that the application of machinery in production really helps farmers to adapt to climate change. This result also reflects the subjective assessment of the farmers themselves.

Finally, potential technical solution for lime farming in the Mekong River Delta was also proposed, including mechanization for small and medium farm and mechanization considerations for plant care (irrigation and fertilizing using open hydroponic system and accurate spraying). Furhtermore, the semi-mechanization harvesting systems and appropriate storage facility and suitable packaging are highly recommeded for improving the quality of lime fruit.

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