FARMING SYSTEMS OPTIONS TO ENHANCE THE PRODUCTION AND SUSTAINABILITY OF CASSAVA IN NORTHWEST CAMBODIA

Sophanara Phan

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science Program in Crop Science

Suranaree University of Technology

Academic Year 2020

ทางเลือกระบบการเกษตรเพื่อเพิ่มประสิทธิภาพการผลิตมันสำปะหลังอย่างยั่งยืนในภาคตะวันตกเฉียงเหนือของกัมพูชา

นายสุพาณารา พาน

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาพืชศาสตร์
มหาวิทยาลัยเทคโนโลยีสุรนารี
ปีการศึกษา 2563

FARMING SYSTEMS OPTIONS TO ENHANCE THE PRODUCTION AND SUSTAINABILITY OF CASSAVA IN NORTHWEST CAMBODIA

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

Thesis Examining Committee

(Asst. Prof. Dr. Thitiporn Machikowa)
Chairperson

(Asst. Prof. Dr. Sodchol Wonprasaid)
Member (Thesis Advisor)

(Asst. Prof. Dr. Teerayoot Girdthai)
Member

(Dr. Stephanie Clare Montgomery)
Member

(Assoc. Prof. Flt. Lt. Dr. Kontorn Chamniprasart)
Vice Rector for Academic Affairs and Internationalization

(Prof. Dr. Neung Teaumroong)
Dean of Institute of Agricultural Technology

พาน สุพาณารา : ทางเลือกระบบการเกษตรเพื่อเพิ่มประสิทธิภาพการผลิตมันสำปะหลังอย่างยั่งยืนในภาคตะวันตกเฉียงเหนือของกัมพูชา (FARMING SYSTEMS OPTIONS TO ENHANCE THE PRODUCTION AND SUSTAINABILITY OF CASSAVA IN NORTHWEST CAMBODIA) อาจารย์ที่ปรึกษา : ผู้ช่วยศาสตราจารย์ ดร. สุดชล วุ้นประเสริฐ, 114 หน้า.

เกษตรกรส่วนใหญ่ทางตะวันตกเฉียงเหนือของกัมพูชา ปลูกมันสำปะหลังในฤดูร้อนช่วงเดือนมีนาคมและเมษายน ใช้วิธีปลูกโดยยกร่องปลูกปักในแนวตั้ง ซึ่งแตกต่างจากเกษตรกรในจังหวัดทางตะวันออกของกัมพูชา ซึ่งปลูกมันสำปะหลังในเดือนพฤษภาคมหรือมิถุนายนที่มีสภาพ อากาศเย็นและชื้น วิธีปลูกไม่มีการยกร่องปลูก วางท่อนพันธุ์ในแนวนอน ซึ่งในปัจจุบันยังไม่มีคำแนะนำอย่างเป็นทางการสำหรับระยะเวลาการปลูกมันสำปะหลัง และวิธีการปลูกมันสำปะหลังในพื้นที่นี้ การศึกษานี้มีวัตถุประสงค์คือ 1) เพื่อประเมินผลของระยะเวลาปลูกมันสำปะหลังต่อผลผลิตโดยใช้ระบบการปลูก 2 แบบ (การปลูกไถพรวน และแบบไม่ไถพรวน) และมีเวลาปลูก 3 เดือน (เมษายน พฤษภาคม และมิถุนายน) 2) ประเมินวิธีการปลูกมันสำปะหลังซึ่งประกอบด้วย การปลูกโดยวางท่อนพันธุ์ในแนวนอน และแนวตั้งบนพื้นที่ที่มีการไถพรวนและยกร่องปลูก ยกร่อง และไม่มีการไถพรวน

ทำการทดลอง 2 การทดลองที่จังหวัดพระตะบอง และจังหวัดไพลิน ในช่วงปี 2017-18 และ 2018-19 การทดลองที่ 1 วางแผนการทดลอง split plot design จำนวน 4 ซ้ำ มีสองปัจจัย ได้แก่ : main plot คือวันที่ปลูก (M1 = เดือนเมษายน M2 = เดือนพฤษภาคม, M3 = ปลูกในเดือนมิถุนายน) และ sub plot คือวิธีการปลูก (S1 = ไถพรวน S2 = ไม่ไถพรวน) ผลการทดลองสองปีในจังหวัดพระตะบอง พบว่าการเลื่อนการปลูกไปเป็นเดือนพฤษภาคม และมิถุนายนให้ผลผลิตสูงกว่าการปลูกในเดือนเมษายนทั้งการปลูกแบบไถพรวน และแบบไม่ไถพรวน อย่างไรก็ตามผลการทดลองที่ไพลินแห่งแรกในปี 2560-2561 พบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญ หรือปฏิสัมพันธ์ระหว่างกรรมวิธีต่างๆ ส่วนผลการทดลองในแห่งที่ 2 ของอำเภอไพลินในปี 2561-2562 พบว่ากรรมวิธีทั้งหมดที่ปลูกในเดือนเมษายน และพฤษภาคมให้ผลผลิตสูงกว่าในเดือนมิถุนายนอย่างมีนัยสำคัญ ซึ่งตรงกันข้ามกับผลการทดลองที่อำเภอสอมโลด เมื่อนำผลทั้งหมดนี้มาพิจารณา จะเห็นว่าเวลาปลูกที่เลื่อนไปในเดือนพฤษภาคม และมิถุนายน ทำให้ผลผลิตมันสำปะหลังดีขึ้น และลดความเสี่ยงต่อการสูญเสียของผลผลิตเมื่อเปรียบเทียบกับการปลูกในปัจจุบัน

การทดลองครั้งที่ 2 วางแผนการทดลองแบบ split plot design จำนวน 4 ซ้ำ มีสองปัจจัย ได้แก่ : main plot คือการไถพรวน (M1 = ยกร่อง M2 = ไม่ยกร่อง, M3 = ไม่ไถพรวน) และ subplot คือวิธีการปลูก (S1 = การปลูกในแนวตั้ง S2 = การปลูกแนวนอน) ผลการทดลองที่อำเภอสอมโลด พบว่าวิธีการปลูกแบบยกร่องที่มีการปลูกในแนวตั้ง หรือแนวนอนเป็นวิธีการที่ให้ผลผลิตสูงสุด นอก

จากนี้ยังพบว่าวิธีการปลูกแบบไม่ไถพรวนเป็นวิธีการที่ให้ผลผลิตต่ำที่สุด และวิธีการลดการไถพรวนที่ไม่มีการยกร่องปลูกให้ผลผลิตระหว่างกลาง อย่างไรก็ตามผลจากปีที่สองสนับสนุนผลการทดลองที่พบในครั้งแรก โดยผลการทดลองที่ไพลินแห่งแรกในปี 2560-2561 พบว่าไม่มีความแตกต่างอย่างมีนัยสำคัญสำหรับวิธีการต่างๆ นอกจากนี้ผลการทดลองที่ไพลินแห่งที่สองในฤดูกาล 2561-2562 สอดคล้องกับการทดลองที่อำเภอสอยดาว ที่พบว่าการยกร่องปลูกแบบเดิมให้ผลผลิตสูงกว่าการไม่ไถพรวน แต่ไม่แตกต่างกันทางสถิติกับการปลูกแบบไม่ยกร่อง งานวิจัยนี้ชี้ให้เห็นว่าการปลูกแบบแนวตั้งบนร่องปลูก แบบเดิมเป็นวิธีการปฏิบัติที่ดี และให้ผลตอบแทนสูงสุดเหมาะสำหรับเกษตรกรที่จะต้องปฏิบัติต่อไป

สาขาวิชาเทคโนโลยีการผลิตพืช ลายมือชื่อนักศึกษา__________

ปีการศึกษา 2563 ลายมือชื่ออาจารย์ที่ปรึกษา__________

SOPHANARA PHAN : FARMING SYSTEM OPTIONS TO ENHANCE THE PRODUCTION AND SUSTAINABILITY OF CASSAVA IN NORTHWEST CAMBODIA. THESIS ADVISOR : ASST. PROF. SODCHOL WONPRASAID, Ph.D., 114 PP.

TIME OF PLANTING/PLANTING METHODS/CASSAVA YIELD/HORIZONTAL PLANTING/VERTICAL PLANTING/CONVENTIONAL HILL/NO TILL PRACTICE

Most farmers in Northwest Cambodia plant cassava in the hottest months of the dry season (March or April). Also in Northwest Cambodia, cassava stems are planted vertically in a hilled up bed. This study was conducted with the objectives of (1) evaluating the effects of time of planting on cassava yield under two different farming practices (conventional hill and no till) and three different months of planting (April, May and June) (2); investigating different planting methods in relation to horizontal versus vertical stem placement along with land preparation methods of conventional hilled, reduced tillage and no tillage. Two experiments were conducted at Samlout District, Battambang Province and Pailin District, Pailin Province during in 2017-18 and 2018-19 seasons. The first experiment was arranged in a split plot design consisting of six treatments with four replications. There are two factors including: Main plot was date of planting (M1 = Planting in April, M2 = Planting in May, M3 = Planting in June), and Sub plot was planting method (S1 = Conventional hill, S2 = No till). Generally the results of two years research at Samlout found that delaying sowing time until May or June produced reliably higher yields than planting in April for either planting method. However, results at the Pailin site in 2017-18 found that, there were no significant differences or interaction in yields between any of the treatments. Results at the Pailin, in the 2018-19, found that all treatments planted in April and May produced significantly higher yield than either practice in June, which is in contrast to the results at Samlout. Our research recommended that the altered time of planting in May and June may improve cassava yield and reduce the risk of crop failure. The second experiment were conducted at Samlout District, Battambang Province and Pailin Province during in 2017-18 and 2018-19 seasons. The second experiment were arranged in a split plot design consisting of six treatments with four replications. There are two factors including: Main plot was tillage (M1 = Conventional hill, M2 = Conventional flat, M3 = No till), and Sub plot was planting method (S1 = Vertical planting, S2 = Horizontal planting). Results at the Samlout site consistently found that the conventional hilled up planting method with either vertical or horizontally planted stakes were the highest yielding treatments. However, results from the second year, supported the initial findings. Results at the Pailin site in 2017-18 found that, there were no significant differences yield for any treatments. Additionally, results at the Pailin site in 2018-19 season concurred with Samlout that the conventional hilled treatments yielded significantly higher than the no-till treatments but not statistically different to the conventional flat treatments. This research indicates that conventional hill vertical planting was the most practical and economical method for farmers to continue to practice.

School of Crop Production Technology — Student's Signature ____________

Academic Year 2020 — Advisor's Signature ____________

ACKNOWLEDGEMENTS

This research was conducted as part of the ACIAR funded project ASEM/2013/003 'Uptake of agricultural technologies and best practices amongst farmers in Battambang and Pailin provinces.' I was jointly funded for my Masters study by this ACIAR project along with the scholarship programme at Suranaree University of Technology (SUT), Nakorn Ratchisema, Thailand. I would like to express my deepest gratitude to all the following individuals:

Asst. Prof. Dr. Sodchol Wonprassaid, my on campus thesis supervisor, for providing me with a great scholarship and the opportunity to study a Master's degree at SUT. His kind support, understanding, patience and the numerous hours he has spent editing this thesis and other papers for me is invaluable.

Dr. Stephanie Montgomery, my thesis co-supervisor, for her support and carrying out all the experiments for two year, shared knowledge and experiences, editing this paper, sincerely thank for her encouragement and technical assistance, I am greatly appreciative.

Asst. Prof. Dr. Thitiporn Machikowa and Asst. Prof. Dr. Teerayoot Girdthai, for allowing me to participate in their statistics analysis and crops science classes.

I am extremely grateful to ACIAR for funding support for this research and deepest thankful to Suranaree University of Technology (SUT) for providing me with a great scholarship.

I am profoundly thanks to Matthew Tighe Associate Professor-School of Environmental and Rural Science, University of New England Armidale Australia, for his support screening data and data analysis.

My sincere gratitude goes to Mr. Eric, Ms. Sokunthea, Ms. Manika and other friend for their helping in the field experiment site and invaluable time in this research.

My appreciation to my mother and parents-in-law, brother and sister, for their inspiration and assistance with looking after my family. I would also like to thank my lovely wife for her continued understanding, patience and for taking care of our baby whilst I was away.

Sophanara Phan

CONTENTS

Page

ABSTRACT IN THAI I
ABSTRACT IN ENGLISH III
ACKNOWLEDGEMENT V
CONTENTS VII
LIST OF TABLES XIII
LIST OF FIGURES XVI
LIST OF ABBREVIATIONS XVIII
CHAPTER
I INTRODUCTION 1
1.1 General introduction 1
1.2 Research objectives 4
1.3 Research hypothesis 4
1.4 Scope of the study 4
II LITERATURE REVIEW 5
2.1 Current cassava production in Asia 5
2.2 Cassava situation in Cambodia 6
2.3 Trends of upland crops grown in Northwest Cambodia 8
2.4 Why farmers grow cassava 10
2.5 Climate in Northwest Cambodia 10

CONTENTS (Continued)

Page

2.6 Soil properties in Northwest Cambodia....................................12

2.7 Analysis of nutrient balance....................................12

2.8 Cassava nutrient requirement....................................13

2.9 Cassava planting time....................................15

2.10 Cassava planting method....................................16

III RESEARCH PROCEDURE....................................18

3.1 Site selection....................................18

3.2 Calendar and trial sites....................................35

3.3 Rainfall distribution....................................36

3.4 Soil properties....................................39

3.5 Materials and methods....................................40

3.5.1 Experimental design....................................40

3.5.2 Chemical fertilizer....................................45

3.5.3 Land preparation....................................45

3.5.4 Planting material....................................46

3.5.5 Planting method....................................46

3.5.6 Weed control....................................46

3.5.7 Insect pests and diseases on cassava....................................46

3.5.8 Harvesting....................................47

3.5.9 Data collection....................................47

3.5.10 Data analysis....................................49

CONTENTS (Continued)

Page

IV RESULTS AND DISCUSSION...50

4.1 Results of time of planting trials..50

4.1.1 Effects of time of planting on cassava yield at the Samlout site in 2017-18 50

4.1.1.1 Soil moisture measurement...............................50

4.1.1.2 Cassava plant components at the Samlout site in 2017-18...52

4.1.1.3 Production costs and gross margin 53

4.1.2 Effects of time of planting on cassava yield at the Samlout site in 2018-19 54

4.1.2.1 Soil moisture measurement...............................55

4.1.2.2 Cassava plant components at the Samlout site in 2017-18...56

4.1.2.3 Production costs and gross margin 57

4.1.3 Effects of time of planting on cassava yield at the Pailin site in 2017-18 58

4.1.3.1 Soil moisture measurement...............................59

4.1.3.2 Cassava plant components at the Samlout site in 2017-18...60

4.1.3.3 Production costs and gross margin 61

CONTENTS (Continued)

Page

4.1.4 Effects of time of planting on cassava yield at the Pailin site in 2018-19 62

4.1.4.1 Soil moisture measurement....63

4.1.4.2 Cassava plant components at the Samlout site in 2018-19....64

4.1.3.3 Production costs and gross margin 65

4.2 Results of cassava planting method trials 66

4.2.1 Results of planting methods on cassava yield at the Samlout site in 2017-18....66

4.2.1.1 Soil moisture measurement....67

4.2.1.2 Cassava plant components at the Samlout site in 2017-18....68

4.2.1.3 Production costs and gross margin 69

4.2.2 Results of planting methods on cassava yield at the Samlout site in 2018-19....70

4.2.2.1 Soil moisture measurement....71

4.2.2.2 Cassava plant components at the Samlout site in 2018-19....72

4.2.2.3 Production costs and gross margin 73

4.2.2.4 Soil bulk density 74

CONTENTS (Continued)

Page

4.2.3 Results of planting methods on cassava yield at the Pailin site in 2017-18 75
4.2.3.1 Soil moisture measurement 76
4.2.3.2 Cassava plant components at the Pailin site in 2017-18 77
4.2.3.3 Production costs and gross margin 78
4.2.4 Results of planting methods on cassava yield at the Pailin site in 2018-19 79
4.2.4.1 Soil moisture measurement 80
4.2.4.2 Cassava plant components at the Pailin site in 2018-19 81
4.2.4.3 Production costs and gross margin 82
4.2.4.4 Soil bulk density 83
4.3 Discussion 84
4.3.1 Results of time of planting trials for two years season at Samlout and Pailin site 84
4.3.2 Results of cassava planting method for two years at Samlout and Pailin site 87
V CONCLUSION 90
REFFERRECE... 93

CONTENTS (Continued)

Page

APPENDIX 101

APPENDIX A Results of time of plant all trials for 2 year 101

APPENDIX B Results of cassava planting method all trials for 2 year.... 106

APPENDIX C Field activities all trial sites. 111

BIOGRAPHY 114

LIST OF TABLES

Table **Page**

2.1 Cassava production, area, and yield in the world, on three continents, and in Asian countries in 2011......6
2.2 Nutrient uptake and removal by cassava......15
2.3 Fresh root yield (t/ha) of recommended cassava cultivars when planted in different periods at Rayong Field Crops Research Center, Thailand, 1987-1988......16
3.1 Cassava planting date and harvested for all trial sites......36
3.2 Summary of averaged climate data during the research period from 2017 to 2019 at Pailin and Samlout......38
3.3 The chemical and physical properties of experimental soil for all trials in Samlout and Pailin district......39
3.4 Plot plan of alternative month of planting cassava for Smalout site for 2 year......40
3.5 Treatments of alternative month of planting cassava for Samlout site for 2 year......41
3.6 Plot plan of alternative month of planting cassava at the Pailin site in 2017-18......41
3.7 Treatments of alternative month of planting cassava at the Pailin site in 2017-18......41

LIST OF TABLES (Continued)

Table **Page**

3.8 Plot plan of alternative month of planting cassava at the Pailin site in 2018-19 42

3.9 Treatments of alternative month of planting cassava at the Pailin site in 2018-19 42

3.10 Plot plan of cassava planting method trial at Samlout site for 2 year 43

3.11 Treatments of cassava planting method trial at Samlout site for 2 year 43

3.12 Plot plan of cassava planting method trial at the Pailin site in 2017-18 44

3.13 Treatment of cassava planting method trial at the Pailin first site in 2017-18 44

3.14 Plot plan of cassava planting method trial at the Pailin site in 2018-19 44

3.15 Treatment of cassava planting method trial at the Pailin site in 2018-19 45

4.1 Volumetric soil moisture readings throughout the growing season at the Samlout site in 2017-18 52

4.2 Cassava plant components measured at the Samlout site in 2017-18 53

4.3 Gross margin return at the Samlout site in 2017-18 54

4.4 Volumetric soil moisture readings throughout the growing season at the Samlout site in 2018-19 56

4.5 Cassava plant components at the Samlout site in 2018-19 57

4.6 Gross margin return at the Samlout site in 2018-19 58

4.7 Volumetric soil moisture readings throughout the growing season at the Pailin site in 2017-18 60

LIST OF TABLES (Continued)

Table **Page**

4.8 Cassava plant components at the Pailin site in 2017-18 61
4.9 Production costs and gross margin return at the Pailin site in 2017-18 62
4.10 Volumetric soil moisture readings throughout the growing season 64
4.11 Cassava plant components at the Pailin site in 2018-19 65
4.12 Production costs and gross margin return at the Pailin site in 2018-19 66
4.13 Volumetric soil moisture readings throughout the growing season 68
4.14 Cassava plant components at the Samlout site in 2017-18 69
4.15 Production costs and gross margin return at the Samlout site in 2017-18 70
4.16 Volumetric soil moisture readings throughout the growing season at the 72
4.17 Cassava plant components at the Samlout site in 2018-19 73
4.18 Gross margin return at the Samlout site in 2018-19 74
4.19 Soil bulk density at the Samlout site in 2018-19 75
4.20 Volumetric soil moisture readings throughout the growing season at 77
4.21 Cassava plant components at the Pailin site in 2017-18 78
4.22 Production costs and gross margin return at the Pailin site in 2017-18 79
4.23 Volumetric soil moisture readings throughout the growing season at 81
4.24 Cassava plant components at the Pailin site in 2018-19 82
4.25 Production costs and gross margin return at the Pailin site in 2018-19 83
4.26 Soil bulk density at the Pailin site in 2018-19 84

LIST OF FIGURES

Figure **Page**

2.1 Eight year production trends of maize and cassava in Pailin province 9

2.2 Eight year production trends of maize and cassava in Battambang province 9

2.3 Monthly rainfall and temperature at Battambang and Pailin province............ 11

3.1 Location of the experimental sites at Samlout district and Pailin Province 35

4.1 Effects of time of planting on cassava yield at the Samlout site in 2017-18 season 51

4.2 Effects of time of planting on cassava yield at the Samlout site in 2018-19 season 55

4.3 Effects of time of planting on cassava yield at the Pailin site in 2017-18 season 59

4.4 Effects of time of planting on cassava yield at the Pailin site in 2018-19 season 63

4.5 Effects of planting methods on cassava yield at the Samlout site in 2017-18 season 67

4.6 Effects of planting methods on cassava yield at the Samlout site in 2018-19 season 71

LIST OF FIGURES (Continued)

Figure **Page**

4.7 Effects of planting methods on cassava yield at the Pailin site in 2017-18 season 76

4.8 Effects of planting methods on cassava yield at the Pailin site in 2018-19 season 80

LIST OF ABBREVIATIONS

MAFF	=	Ministry of Agriculture, Forestry and Fisheries
MOC	=	Ministry of Commerce
MOP	=	Ministry of Planning
WB	=	World Bank
PDA	=	Provincial Department of Agriculture
CARDI	=	Cambodia Agricultural Research and Development Institute
FAO	=	Food and Agriculture Organization
UNDP	=	United Nation Development Programme
GDP	=	Gross Domestic Product
NW	=	Northwest Cambodia
ES	=	Eastern Cambodia
TOP	=	Time of planting
PM	=	Planting Method
CH	=	Conventional Hill
CF	=	Conventional Flat
NT	=	No till
GM	=	Gross Margin
Hor	=	Horizontal planting
Vert	=	Vertical planting
Apr	=	April
May	=	May

LIST OF ABBREVIATIONS (Continued)

Jun	=	June
Trt	=	Treatments
Rep	=	Replications

CHAPTER I

INTRODUCTION

1.1 General introduction

Cassava is a tropical root crop, originally from Latin America. It is a potentially useful staple food crop for Africa. Since 2000, the world's annual cassava production has increased by an estimated 100 million tonnes (FAO, 2011). In Asia, the expansion is due to demand for dried cassava and starch for use in livestock feed and industrial uses; and in Africa, the demand stems from expanding urban markets for cassava food production (Howeler, 2006). In Cambodia currently, upland crop production has played an important role in contributing to household incomes in upland areas, accounting for approximately 4% of the national GDP (MAFF, 2018). Among upland crops, cassava has gained the most popularity with Cambodian farmers. It is now the second largest crop produced in Cambodia after rice; and is cultivated in almost all provinces (MAFF, 2018). The production of the crop has rapidly increased in the past decade because of high market demand for export and domestic uses, and relatively high price (Kem, 2017).

The target areas of this study are the upland farming areas of Battambang and Pailin Provinces, which are located in Northwest Cambodia. Landscapes in this region have been transformed in recent decades, due to large-scale deforestation with a rapid transformation from native forests to cash crops, including sesame, maize, rubber, and other crops (PDA-BB, 2017). From 2002 and 2011, most of farm land in this region was sown to cash crops comprising mainly of maize, mungbean, soybean and sesame (Montgomery et al., 2016).

The expansion of profitable smallholder commercial cassava and maize production established a viable pathway for improving farming livelihood. Unfortunately however, farming practices in this region have transitioned from an originally crop species diverse farming system to monoculture cropping and thus now the regions farmers face challenges related to soil erosion, declining soil fertility and regular crop failure (Montgomery et al., 2016). The rapid expansion in the area under cassava production has resulted in problems such as reduced crop diversity, declining soil fertility and soil erosion (Howeler, 2000). Currently, declining cassava root yields in the region represent a significant problem, with an estimated decline of 2.6 tons/ha/year from 2011 to 2016, due to climate variability, pests and diseases threats, lack of crop rotation, and planting cassava with little or no fertilizer application (MAFF-UNDP, 2015). Lack of suitable high-yielding varieties for agro-ecological conditions and shortage of healthy and good-quality planting materials are main constraints of cassava production (Wenjun at al., 2016). Management of soil fertility and soil erosion are of critical importance in sustainable cassava production, especially since it is often grown on less fertile soils usually with little or no fertilizer applied; and on sloping land in the upland areas (De Costa et al., 2006).

Most farmers in Northwest Cambodia plant cassava in the hottest months of the dry season (March or April). This is in contrast to farmers in Kampong Cham Province, in Eastern Cambodia, where they plant cassava in the slightly cooler and wetter months of May or June (Wenjun et al., 2016). Currently, farmers are aware that these practices lead to a high risk of crop failure, and they need to adapt their farming system to the changed climate conditions in order to maintain yields (Toouch et al., 2016). One way to reduce the impact of drought in the early wet season is to keep crop residues in the field and on the soil surface. If farmers reduce the amount of ploughing, burning and retain crop residues, as well as mulching, and changing their planting dates they can reduce the probability of crop failure (Montgomery et al., 2016).

Recently crop failures in Samlout and Pailin in Northwest Cambodia might be caused by climate change (Touch et al., 2016). At Pailin in 2015; about 3,800 ha out of 6,850 ha (55.5%) and at Samlout 4,578 ha out of 8,057 ha (56.82%) of early wet season corn was lost because of drought (PDA-BB, 2017). The same has happened again in 2016 with an estimated 10,289 ha of cassava have also been affected where farmers have replanted cassava two to three times before significant rainfall was received in Samlout and Pailin (PDA-BB, 2017). Small-scale farmers are losing a lot of money due to crop failures in the early wet season (PDA-BB, 2017).

Furthermore, it has been observed that cassava planting methods differ between farmers in Pailin and Battambang Provinces and farmers in Kampong Cham Province (Wenjun et al., 2016). In Northwest Cambodia, cassava stems are planted vertically in a hilled up bed, whereas in Kampong Cham, Eastern Cambodia, cassava is planted horizontally in furrows on land that is not hilled up (Wenjun et al., 2016). The horizontal planting method produced lower root yields than vertical planting in the sandy clay loam soils of Rayong Province in Thailand (Tongglum et al., 2001). Similar results were obtained in Cambodia where vertical planting produced higher yield compared to the horizontal planting method (Sopheap et al., 2008).

1.2 Research objectives

This thesis research was conducted in Battambang and Pailin Provinces, Northwest Cambodia. The objectives were: 1) to determine if it is more feasible and less risky to grow cassava at alternative months of planting compared to usual farmer practice in Northwest Cambodia of planting in Feb/March/April; and within this system compare no till conservation agriculture versus conventional planting on hills. 2) To investigate the different planting methods in relation to horizontal versus vertical stem placement along with land preparation methods of conventional hilled, reduced tillage and no tillage.

1.3 Research hypotheses

This research was focused on improving the sustainability of cassava production in Northwest Cambodia.

1.3.1 The risk of crop failure in the early wet season may be reduced by delaying planting time to May and June rather than planting in April.

1.3.2 Cassava yield may be improved by implementing an alternative planting method and land preparation.

1.4 Scope of the study

The scope of this study involved evaluating the effects of land preparation practices in conjunction with the time of planting and investigating different planting methods in relation to horizontal versus vertical stem placement on cassava yield in Northwest Cambodia. Only one cassava variety 89 (CMR 89), was planted in both trials under rain fed conditions with no irrigation.

CHAPTER II

LITERATURE REVIEW

2. 1 Current cassava production in Asia

Cassava was a minor crop in Asia in the 1970's and 1980's, yet today it is a major crop in the region (Hershey, 2000). In Asia in 1999, average cassava yields were approximately 14 t/ha and accounted for 20% of the area of cassava harvested in the world (Onwueme, 2002). However over the course of 10 years, cassava in Asia increased to 35% of global production (Ong et al., 2018). In Asia contains 30% of the world wide cassava production, with the other major commodities in the region being maize and paddy rice rice (FAO, 2011). China is a main cassava importer in Asia, importing about 80% of its domestic requirement for the use of raw material for the production of ethanol, animal feed and for processed food (FAO, 2011). The primary reason why cassava production area is increasing is in response to food, industrial use and export demand, and the second reason is the crop's resistance to drought, pests and diseases (Howeler, 2004a).

In Vietnam, in the decade from 1980 to 1990, cassava production declined due to increased rice production and a depressed economy. However in the millennium decade, Vietnam's cassava production increased from approximately 2 million tons in 2000, to 8.5 million tons in 2009, in order to meet export cassava starch demand in China (Howeler, 2004a). In both Vietnam and Thailand, cassava yield increases over the past 10 years may be attributed to joint efforts to distribute and demonstrate new varieties with improved yield and high starch content and adaption of improved farming practices such as fertilizer application and soil improvement (Howeler, 2004b). Currently in Thailand, new cassava varieties are grown in almost 100% of the production areas, and 80-90% of farmers apply chemical fertilizer fertilizer (Howeler, 2000). In Vietnam; 60% of the production areas are growing new varieties with 80% of farmers applying chemical fertilizer and manure (Howeler, 2000).

Table 2.1 Cassava production, area, and yield in the world, on three continents, and in Asian countries in 2011.

Continents/Countries	**Production**	**Cultivated area**	**Yield**
World	252,204	19,644	12.84
Africa	140,966	13,047	10.80
Americas	34,363	2,668	12.87
Asia	76,681	3,913	19.60
Cambodia	4,368	205	21.29
China	4,515	276	16.37
India	8,076	221	36.48
Indonesia	24,010	1,183	20.30
Lao PDR	743	31	23.83
Malaysia	39	3	13.43
Myanmar	615	47	13.09
Philippine	2,210	221	9.99
Sri Lanka	293	24	12.10
Thailand	21,219	1,135	19.30
Timor-Leste	22	6	3.84
Vietnam	9,876	560	17.63

Source: FAOSTAT, (2011).

2.2 Cassava situation in Cambodia

Cambodia is a South East Asian developing country with the total area of 181,035 km^2 and a population of 16.6 million. Approximately 77% of the population live in rural areas and about 40% of the population work in farming, down from approximately 80% in 1993 (NSDP, 2009). Agriculture continues to play an important role in Cambodia's economic growth, accounting for 22% of GDP (MAFF, 2015). The Ministry of Agriculture, Forestry and Fisheries (MAFF) is in a position to promote crop diversification, commercial production and agro-industries in order to help improve rural household incomes and reduce poverty in line with the national development policies of the government (Murshid, 1998). Over the past decade, Cambodia's agricultural gross production grew by 8.7% during 2004-2012 mainly because of increased higher paddy rice production, along with a significant increase in maize 20%, cassava 51%, sugarcane 22% and vegetable 10% production (Mund, 2011).

In Cambodia, cassava is cultivated in 13 provinces, with more than 570,000 hectares that produces around 13 million tonnes of produce a year, which makes it the second largest crop after rice (MAFF, 2018). Government plans for a new export cassava policy will help transform the cassava sector, from subsistence agriculture to commercial production, whilst prioritizing improving living standards for farmers (Socheth, 2012).

To ensure income and food sufficiency, many farmers in Northwest Cambodia especially in Battambang and Pailin provinces grow upland crops including cassava, maize, sugar cane and rubber in order to provide additional income to support their family livelihoods (Diepart et al., 2018). In Cambodia, most of the cassava roots produced in the country are exported to the overseas markets through either Thailand or Vietnam; only a small amount of tubers produced is used in local cassava processing in the country (Howeler, 2006).

2.3 Trends of upland crops grown in Northwest Cambodia

Battambang and Pailin Provinces are located in Northwest Cambodia, in a region which since 1999 has seen a significant increase in the area sown to upland crops, principally maize, mungbean, soybean and sesame (PDA-BB, 2017). In Battambang and Pailin Provinces between 1999 and 2009, the area of maize cultivated increased from 14,000 to 150,000 ha, with this rapid expansion due largely to deforestation and export demand. However, in Pailin province, the area of maize production has decreased from 54,860 ha to 13,189 ha in the years 2010-2017, whilst the area of cassava cultivated in this Province has increased from 14,509 to 58,907 ha during the same period with the transfer of crop domination evident in 2012 (PDA-BB, 2017) (Figure 2.1). Cassava production in Battambang Province (Figure 2.2) increased from 51,734 ha to 105,472 ha from 2010 to 2017, with the shift in majority of area planted to cassava rather than maize, occurring two years later in this province than in Pailin Province (PDA-PL, 2017).

Currently, declining cassava root yields in the region represent a significant problem; yields averaged 36 t/ha in 2011 but had declined to 24 t/ha in the five years to 2016, with an estimated decline of 2.6 tons/ha/year (Wenjun et al., 2016). This reduction in average yields is likely due to climate variability, lack of crop rotation, and growing cassava without applying fertilizer (Montgomery et al., 2017). Decline of soil fertility and changes in rainfall with tillage farming practice, mono-cropping system, no or less fertilizer use, is generally reported in the region (Montgomery et al., 2017). In Pailin and Battambang provinces, a study on yield declining 27%, 29% and 16% of maize, soybean and cassava respectfully was reported from 2008 to 2012, with

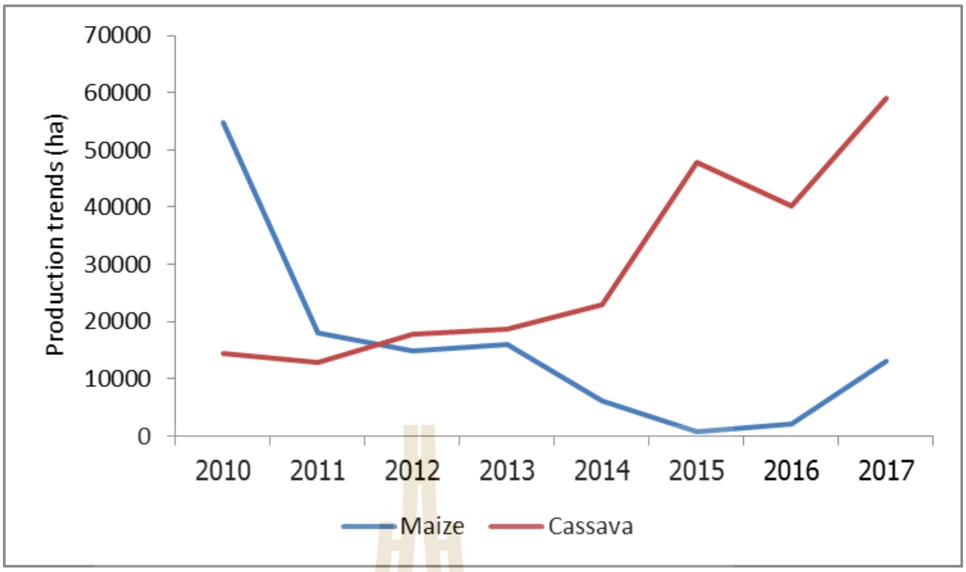

Figure 2.1 Eight year production trends of maize and cassava in Pailin province.

Source: Provincial Department of Agriculture, (2017).

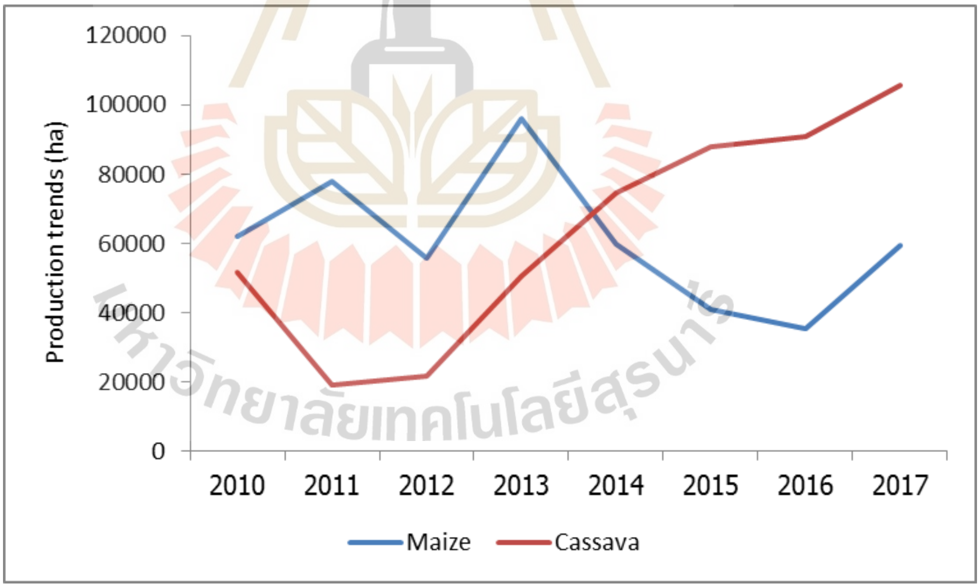

Figure 2.2 Eight year production trends of maize and cassava in Battambang province.

Source: Provincial Department of Agriculture, (2017).

the decline attributed to soil fertility depletion (Touch et al., 2016). In 2008 the average maize yield was approximately 6-7 t/ha in dry grain without using fertilizer on newly reclaimed land. However by 2016, the maize yield had declined to 4 t/ha with $50-100 USD/ha investment in chemical fertilizers (Touch et al., 2016).

2.4 Why farmers grow cassava

Cassava has become an important source of income for farmers in Northwest Cambodia. Fresh and dry tubers are an important export commodity with the majority of market demand stemming from Thailand and Vietnam (Sopheap et al., 2011). The primary upland areas in the region has been grown with several crops including maize, mungbean, soybean, peanut, sesame but in recent years the crop diversification has largely been lost in favour of cassava monoculture (Montgomery et al., 2017). Farmers in Northwest Cambodia growing cassava indicated importance of aspects of growing the crop because it is simple to grow, easy to sell locally at silos and there are established markets (Sopheap et al., 2011). The rapid increase in market demand and associated good price of cassava in Cambodia in recent year, clearly explains why Cambodian farmers choose to grow cassava mainly when compared with other upland crops (Kem, 2017).

2.5 Climate in Northwest Cambodia

At Battambang and Pailin in 2017-18 season (Figure 2.3), data from provincial department of meteorology, showed the average temperature ranges from 25^0C to 31.5^0C with humidity ranging from 51% to 81.5% (PDM, 2017). Both temperature and humidity in Samlout district is similar to Pailin as they are neighboring regions. The mean annual rainfall for Pailin is 1039 mm, while the rainfall at Samlout is higher with an annual mean of 1336 mm (PDM, 2017). The climatic conditions of Samlout-Battambang province and Pailin are affected by the South East Asia Monsoon. Which results in seven months of wet season from May to November and five months of dry season between December and April (Touch et al., 2016). Four seasons can be defined based on temperature and rainfall (Touch et al., 2016) as follows:

1-Early Wet Season, May-July (warm and wet)

2-Late Wet Season, August-October (cool and wet)

3-Early Dry Season, November-January (cool and dry)

4-Late Dry Season, February-April (warm and dry)

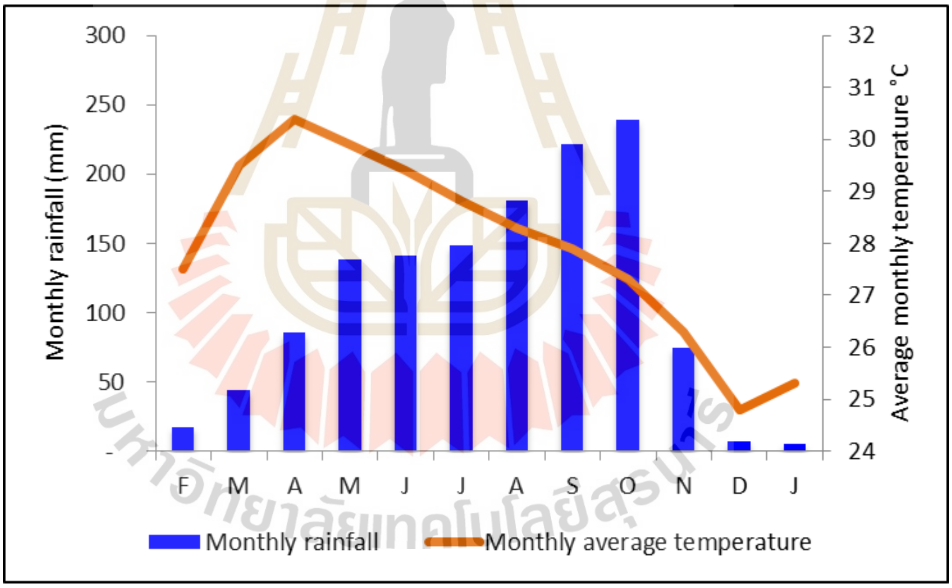

Figure 2.3 Monthly rainfall and temperature at Battambang and Pailin province.

Source: Provincial Department of Meteorology, (2017).

2.6 Soil properties in Northwest Cambodia

Most area of the main upland soils in Northwest Cambodia are on the volcanic plain and limestone plain (Hin et al., 2007). In 2016, under cooperation between an ACIAR project and the Cambodian Agricultural Research and Development Institute (CARDI) a soil survey of 22 sites across Pailin province and Samlout district was conducted. The results showed that the main upland soils are kampong siem (grey-black vertisols) and labansiek (red nitosols), and to a lesser degree, some shallow sandy soils with loamy or clay subsoil (acrisols) (Hin et al., 2007). Paddy field and upland crop cover approximately 20% of the total area, with the soils pH ranging from 6.1 – 6.5 (Hin et al., 2007). In Samlout district, most of upland soils are labansiek and toul samrong (luvisol) with heavy texture and a hard to very hard dry consistency which is also sticky (Hin et al., 2007). In Pailin province most of upland soils are kampong siem with black sandy clay loam texture and soil pH ranges from 7.2 – 7.7 (Bell et al., 2007).

2.7 Analysis of nutrient balance

Soil nutrient balance is the difference between inputs and outputs of mineral nutrient in a unit area within a specific time frame in the system (Stoovogel et al., 1993). It has been well recognized that different production systems may bring about different forms of nutrient imbalance, which will result in different types of problems. In the high input agricultural systems such as in Europe, nutrient balances are often positive, leading to pollution of ground and surface water (Stoovogel et al., 1993). On the contrary, in the low input agricultural systems like in many African countries, nutrient balances are generally negative, resulting in the depletion of soil nutrient stocks and seriously threatening future agricultural production (Stoovogel et al., 1993). Nutrient balance can be used as an important tool in assessing sustainability of land use systems. In relating nutrient balance to land use sustainability, the basic assumption is that the negative balance would indicate a loss of nutrient from the system under the current practice (Stoovogel et al., 1993). If such a practice is continued over a long period, the land quality would be degraded and consequently, sustainability of land productivity would be lowered. A positive balance may also affect land use sustainability if the nutrient is accumulated to the level that it becomes toxic or creates a nutrient imbalance (Howeler, 2001).

The advantage of monitoring nutrient balance is that all major input and output flows of nutrient in the system are measured for better management and forecasting of the nutrient stocks inside the system (Howeler, 2000). Agro-ecosystems with negative nutrient balances have become widespread, especially in Africa and Southeast Asia (Howeler, 2000). However, the loss of nutrients as calculated by nutrient balance alone is not sufficient to be an indicator for the sustainability of an agro-ecosystem, and nutrient balance studies need to incorporate soil nutrient status within the system (Howeler, 1996).

Several studies on nutrient balances had been conducted in many countries around the world including Africa and Europe. These studies have provided useful information not only for improving the land management but also for determining the appropriate strategies for utilizing different types of land in those countries (Howeler, 1996).

2.8 Cassava nutrient requirement

Crop nutrient requirements can be estimated from soil test results. However, different crop types have different nutrient requirements. To achieve a cassava root yield of 35.7 t/ha, the amount of nutrient removed is estimated to be 55 kg N, 13.2 kg P, and 112 kg K/ha (Putthacharoen et al., 1998). These results calculate that the total amount of K removed is higher than P and N. Continuous cassava planting without fertilizer application will result in a decline in soil fertility and also crop yield reduction. Total nutrient removal per hectare is usually lower than other crops, with the exception of K (Howeler, 2000). However, if stems and leaves are also removed from the field, the extraction of all nutrients increases especially N and Ca (Putthacharoen et al., 1998). In this case nutrient losses may be greater than for other crops, and considerable nutrient inputs in the form of chemical fertilizer or manures are required to maintain a positive nutrient balance. Similar to nutrient removal, total nutrient losses in the eroded soil tend to be high in N and K, but relatively low in P (Putthacharoen et al., 1998). In comparison, nutrient losses in runoff are smaller but tend to be relatively high in Ca and K, followed by N, Mg, and P (Howeler, 2004). Thus, total nutrient losses due to cassava cultivation can be quite high, especially those of N and K, when cassava yields are high, or when the crop is grown on sloping land (Howeler, 2004). In order to maintain a positive nutrient balance, it is important to apply enough fertilizers or manures that are high in N and K, and to use conservation agricultural practices that will reduce runoff and erosion (Putthacharoen et al., 1998).

To maintain a positive balance of all three major nutrients, in Vietnam, it is recommended that farmers apply less P and farmyard manure (< 5-10 t/ha), but apply additional K in the form of chemical fertilizers. In Thailand, it is recommended that farmers shift from applying 15-15-15 (N-P_2O_5-K_2O) to the use of a compound fertilizer high in K and N such as 15-7-18 (N-P_2O_5-K_2O), applying at least 200 kg/ha to sustain an average cassava root yield of about 15 t/ha. The quantities of N, P and K that need to be taken up by a cassava plant to obtain a fresh root yield from 18 to 45 t/ha are presented in table 2.2 (Howeler, 2004).

Table 2.2 Nutrient uptake and removal by cassava.

Yield	Plant	N	P	K
t/ha		kg/ha		
45	Fresh roots	62	23	197
	Whole plant	202	73	343
37	Fresh roots	67	38	122
	Whole plant	198	70	220
18	Fresh roots	32	8	41
	Whole plant	95	23	77

Source: FAOSTAT, (2011).

2.9 Cassava planting time

Planting time for cassava varies considerably between East and Northwest Cambodia, with the majority of farmers in Kampong Cham (Eastern Cambodia) plant cassava in May-June which is contrast to Pailin where planting is usually in March-April (Wenjun et al., 2016). Variation in time of planting between both provinces is probably influenced by differences in weather conditions and rainfall distribution of the two provinces (Wenjun et al., 2016). In general, yields were found to be higher when cassava was planted in May-June, which is in the early part of rainy season (Howeler, 2000). In Rayong Province, Thailand, the highest yields were achieved when cassava was planted from August to November, which is towards the end of wet season. In this case, plants establish well during the latter part of the rainy season, grow slower during the dry season and have an additional period of fast growth during the start of the following wet season (Howeler, 2000).

Table 2.3 Fresh root yield (t/ha) of cassava cultivars when planted in different periods at Rayong Field Crops Research Center, Thailand, 1987-1988.

Planting periods	Cultivars				Average
	Rayong 1	Rayong 3	Rayong 60	Rayong 90	
April-	18.56	19.94	23.31	24.00	21.44 c
June-July	20.81	24.25	27.63	29.31	25.50 ab
August-	22.31	24.44	32.31	27.81	26.75 a
Oct-Nov	21.81	26.62	30.19	26.06	26.19 a
Dec-Jan	19.38	20.38	29.44	23.87	23.25 bc
Feb-	20.75	20.50	26.25	25.44	23.25 bc
Average	20.62 d	22.69 c	28.19 a	26.06 b	

Source: Howeler, (2000).

2.10 Cassava planting method

Usually the farmer practice for planting method in Northwest Cambodia is to plough first and then create a hill in which the cassava stake is placed vertically (Wenjun et al., 2016). Most farmers' preference is to plant cassava into well-prepared soil by hiring a contractor using a 3-disc plough for the first ploughing and then a 7-disc plough for the second pass before hilling up. This practice results in a bare soil surface which causes extensive soil erosion especially on sloping and mountainous terrain (Sopheap et al., 2011). In addition to these factors, the wide plant spacing used, cassava's slow initial growth, and lack of ground cover at the soil surface, can result in high nutrient losses in eroded sediments and runoff (Thomas et al., 2012).

A survey was conducted to identify planting method in Southeast and Northwest Cambodia; the results of which showed that 99.8% of farmers in Pailin province used vertical planting method and planted cassava on the top of hill, while 97.4% of farmers inKampong Cham applied horizontal planting method and planted cassava in furrows (Wenjun et al., 2016). A study evaluated the effects of planting methods (vertical and horizontal) on root yield and nutrient removal of five cassava cultivars (Rayong-7, Rayong-11, Rayong-72, Huaybong-80 and E-dum) in Rayong Province, Thailand showed that vertical planting method gave higher root yield (88.8%) than horizontal and inclined planting in sandy clay loam soil (Tongglum et al., 2001).

CHAPTER III

RESEARCH PROCEDURE

3.1 Site selection

This research study was conducted in Pailin and Battambang Province, Northwest Cambodia at two on-farm trial sites for two years during the year 2017-18 and 2018-19 seasons. In Pailin province, the trial site was conducted in Tek Phos village for the first year experiment in 2017-18; then in 2018-19 the trial site needed to be moved in Pich Kiri village. Which is approximately 3 km away from the original site. It was necessary to conduct the second year of experiments at an alternative location due to the farm owner rescinding the leasing arrangements. Another trial site was conducted in Kompong Touk village, Samlout District, Battambang Province and remained constant for the two year duration of the study. Each experiment was conducted at both locations (Figure 3.1). The trial site in 2017-18 is 157 m above sea level (a.s.l.) with GPS location of 12 53'38.12''N, 102 37'50.74''E; which is approximately 15 km east of Pailin town. The trial site in 2018-19 is 149 a.s.l. with GPS location of 12 58'41.57''N, 102 39'52.63''E; approximately 20 km east of Pailin town. The Samlout trial site is 111 m a.s.l. with GPS location of 12 42'58.56''N 102 46'28.16''E in Kompong Touk village, Samlout District, Battambang Province.

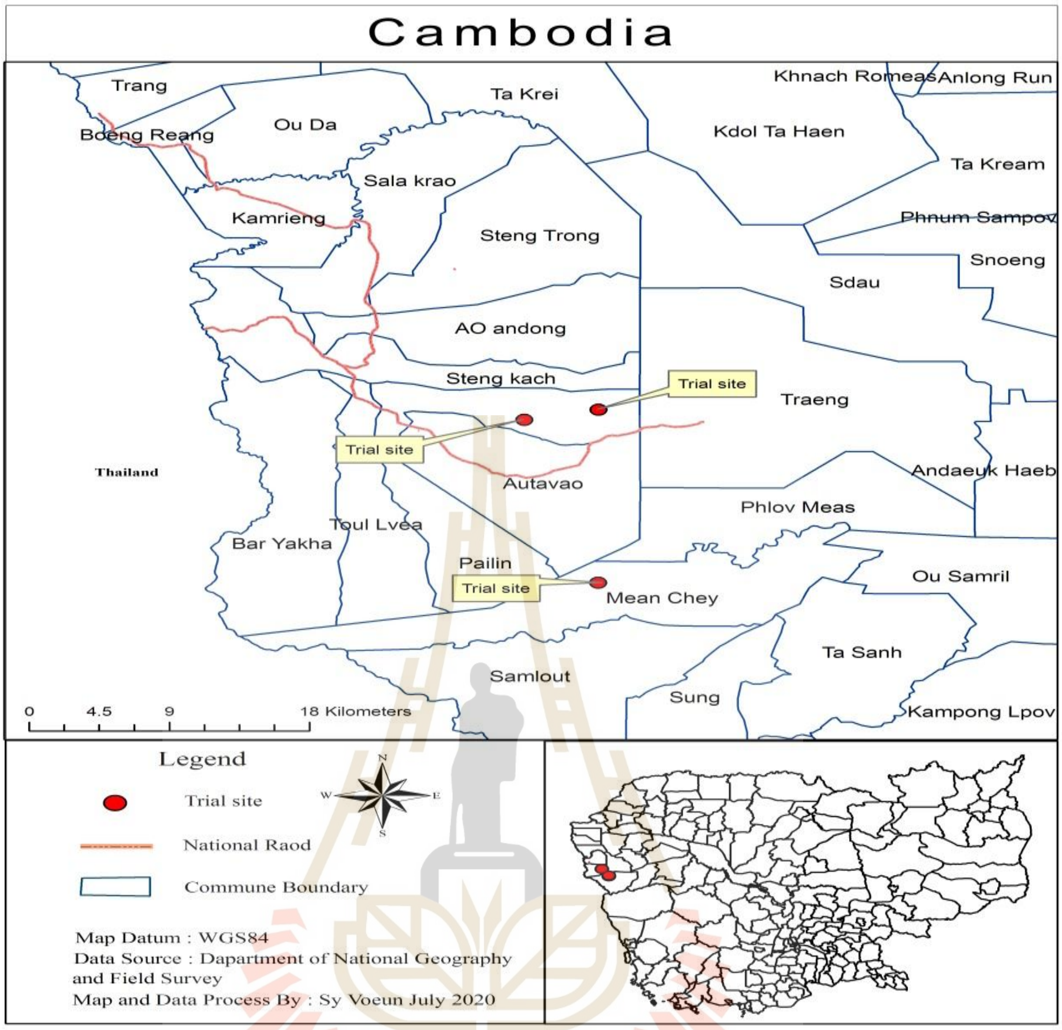

Figure 3.1 Location of the experimental sites at Samlout district and Pailin Province.

3.2 Calendar and trial sites

In the first year; both trial sites of alternative month of planting cassava and cassava planting method trials began planted in 2017 and was harvested in 2018 (Table 3.1) and the second year began planted in 2018 with harvest in 2019. Alternative month of planting cassava trials was started in three different months (April-May-June) of each year. Cassava planting method trials were planted in mid-May of each year with harvest occurring at 10 months after planting for all trials.

Table 3.1 Cassava planting date and harvested for all trial sites.

Year	Trial and Location	Planting date	Harvest date
1	Alternative month of planting cassava-Samlout site in 2017-18	08 April 2017	06 Feb 2018
		16 May 2017	16 Mar 2018
		06 Jun 2017	06 April 2018
1	Alternative month of planting cassava-Pailin site in 2017-18	12 April 2017	10 Feb 2018
		27 May 2017	27 Mar 2018
		14 Jun 2017	13 April 2018
1	Cassava planting method-Samlout site	18 May 2017	16 Mar 2018
1	Cassava planting method-Pailin site	28 May 2017	28 Mar 2018
2	Alternative month of planting cassava-Samlout site in 2018-19	12 April 2018	11 Feb 2019
		17 May 2018	17 Mar 2019
		21 Jun 2018	21 April 2019
2	Alternative month of planting cassava-Pailin site in 2018-19	12 April 2018	12 Feb 2019
		17 May 2018	17 Mar 2019
		21 Jun 2018	21 April 2019
2	Cassava planting method-Samlout site	18 May 2018	18 Mar 2019
2	Cassava planting method-Pailin site	30 May 2018	30 Mar 2019

3.3 Rainfall distribution

Automatic tipping rain gauges (Davis Instruments, Model No. 7852M) containing USB data loggers were installed at each trial site to record daily rainfall. Paired with this was a temperature and relative humidity logger, set to record hourly measurements (Lascar Electronics, Model No. EL-USB2+) per trial site. The mean annual rainfall for two year study in 2017-18 and 2018-19 indicated that there was more rainfall at Samlout than at Pailin site (Table 3.2).

At Samlout site in 2017-18, there was 1829 mm with 392 mm, 1110 mm and 327 mm falling in the pre-monsoon, monsoon and post-monsoon periods. At the same site in 2018-19, there was 1379 mm with 401 mm, 836 mm and 142 mm falling in the pre-monsoon, monsoon and post-monsoon periods. At the Pailin site in 2017-18, there was 1256 mm with 392 mm, 760 mm and 104 mm falling in the pre-monsoon, monsoon and post-monsoon periods. At the Pailin site in 2018-19, there was 1145 mm with 358 mm, 686 mm and 101 mm falling in the pre-monsoon, monsoon and post-monsoon periods.

The mean daily temperature was 28°C at the Samlout site, with a maximum temperature of 41°C in the pre-monsoon period and a minimum temperature of 14°C in the post-monsoon period, consistent for the two-year period. The mean humidity level was 76% which ranged from 24% to 99%.

The mean daily temperature was 28°C at the Pailin site in 2017-18, with a maximum temperature of 43°C in the pre-monsoon period and a minimum temperature of 14°C in the post-monsoon period. The mean humidity levels and ranges for both Pailin sites were the same as for Samlout. The mean daily temperature was 28°C at the Pailin site in 2018-19, with a maximum temperature of 44°C in the pre-monsoon period and a minimum temperature of 14°C in the post-monsoon period.

Table 3.2 Summary of averaged climate data during the research period from 2017 to 2019 at Pailin and Samlout.

Site	Variable	Pre-monsoon Mar-June	Monsoon July-Oct	Post-monsoon Nov-Feb	Annual Total
Samlout 2017-18	Mean Rainfall (mm)	392	1110	327	1829
	Mean Daily Temperature (°C)	29	28	30	29
	Temperature Range (°C)	21-39	20-37	21-41	14-41
	Mean Relative Humidity (%)	65	80	70	72
	Relative Humidity Range (%)	26-98	45-98	24-97	24-98
Pailin site 2017-18	Mean Rainfall (mm)	392	760	104	1256
	Mean Daily Temperature (°C)	30	28	30	29
	Temperature Range (°C)	24-32	27-30	21-43	21-43
	Mean Relative Humidity (%)	25	78	70	57
	Relative Humidity Range (%)	25-88	44-99	29-98	25-99
Samlout 2018-19	Mean Rainfall (mm)	401	836	142	1379
	Mean Daily Temperature (°C)	29	28	30	29
	Temperature Range (°C)	21-39	20-37	21-42	14-42
	Mean Relative Humidity (%)	65	80	70	72
	Relative Humidity Range (%)	26-96	45-99	24-97	24-99
Pailin site 2018-19	Mean Rainfall (mm)	147.9	844.5	101.6	1094
	Mean Daily Temperature (°C)	30	28	30	29
	Temperature Range (°C)	24-32	27-30	21-44	21-44
	Mean Relative Humidity (%)	25	78	70	57
	Relative Humidity Range (%)	25-88	44-99	29-98	25-99

3.4 Soil properties

Most areas of the main grouping of upland soils in Northwest Cambodia are on the volcanic plain and limestone plain (Hin et al., 2005c). The chemical and physical properties of the soil are summarized from lab analyses conducted at Suranaree University of Technology (SUT), Thailand. Results of soil analyses from the experimental sites (Table 3.3) indicated that soils were Labansiek (Ferrosol) and Kampong Siem (Vertosol) (Bell et al., 2005). The Labanseak was red friable silty clay and the Kampong Siem soil was black sandy clay loam. On average, the Ferrosol are higher organic matter and total nitrogen and have lower pH than Vertosol. These clay and clay-loam soils have the capacity to retain significant quantities of plant-available water in dry period (Bell et al., 2005).

Table 3.3 The chemical and physical properties of experimental soil for all trials in Samlout and Pailin district.

Properties	Samlout	Pailin site in 2017-18	Pailin site in 2018-19
pH	6.73	7.83	7.80
EC(mS/cm)	0.199	0.1766	0.234
OM (%)*	3.662	3.018	3.474
Avai.P(mg/kg)	10.390	9.082	7.94
Exc.K(mg/kg)	106.4	63	84.34
Exc.Ca(mg/kg)	4564	2698.4	9211.4
Exc.Mg(mg/kg)	188.6	916.6	1364.4
Texture	Silty clay	Sandy clay	Sandy clay
Miner. N(mg/kg)	76.48	62.24	73.5

3.5 Materials and methods

3.5.1 Experimental design

Experiment 1: Alternative month of planting cassava in NW Cambodia.

This experiment was conducted to evaluate the effects of time of planting cassava on yield. The experiment was arranged in split plot design with six treatments and four replications. Due to the need to plough half of the main treatments with a 4WD tractor, the main treatments of land preparation method are in set strips, with the split plot treatment of time of planting nested within the main plots. At Samlout, trial size was 48 x 40 m and plot size was 8 x 10 m with the row spacing of 1m, and the plant spacing of 1 m. At the Pailin province in 2017-18, the trial area was 48 m x 40 m, the plot site was 8 x 10 m and Pailin site in 2018-19, the trial area was 32 x 48 m and plot size was 8 x 8 m with the row spacing of 1m, and the plant spacing of 1 m. There were two factors including:

- Main plot was date of planting (M1 = Planting in April, M2 = Planting in May, M3 = Planting in June)
- Sub plot was planting method (S1 = Conventional hill, S2 = No till)

Table 3.4 Plot plan of alternative month of planting cassava at the Smalout site for 2 year.

	April		**May**		**June**		
Rep 1	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	40 m
Rep 2	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 3	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 4	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
				48 m			

Table 3.5 Treatments of alternative month of planting cassava at the Samlout site.

Trt	Main plot	Sub plot
M1S1	TOS April	conventional - hill
M1S2	TOS April	no till
M2S1	TOS May	conventional - hill
M2S2	TOS May	no till
M3S1	TOS June	conventional - hill
M3S2	TOS June	no till

Table 3.6 Plot plan of alternative month of planting cassava at the Pailin site in 2017-18.

	April		May		June		
Rep 1	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	40 m
Rep 2	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 3	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 4	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
				48 m			

Table 3.7 Treatments of alternative month of planting cassava at the Pailin site.

Trt	Main plot	Sub plot
M1S1	TOS April	conventional-hill
M1S2	TOS April	no till
M2S1	TOS May	Conventional-hill
M2S2	TOS May	no till
M3S1	TOS June	Conventional-hill
M3S2	TOS June	no till

Table 3.8 Plot plan of alternative month of planting cassava at the Pailin site in 2018-19.

	June		May		April		
Rep 1	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	32 m
Rep 2	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 3	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 4	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
				48 m			

Table 3.9 Treatments of alternative month of planting cassava at the Pailin site.

Trt	Main plot	Sub plot
M1S1	TOS April	conventional-hill
M1S2	TOS April	no till
M2S1	TOS May	conventional-hill
M2S2	TOS May	no till
M3S1	TOS June	conventional-hill
M3S2	TOS June	no till

Experiment 2: Cassava planting method in NW Cambodia.

This experiment was testing the outcomes cassava horizontal vs vertical planting method and conventional hilled up planting vs minimum till flat planting vs no-till flat planting. The experiment was arranged in a split-plot design with six treatments and 4 replications. Both trial sizes were 48 x 40 m and plot size was 8 x 10 m with the row spacing of 1 m, and the plant spacing of 1 m. There were two factors including:

- Main plot was tillage (M1= Conventional hill, M2 =Conventional flat, M3 =No till)
- Sub plot was planting method (S1= Vertical planting, S2= Horizontal planting)

Table 3.10 Plot plan of cassava planting method trial at the Samlout site for 2 year.

	Conventional hilled		Conventional flat		No Till flat		
Rep 1	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	40 m
Rep 2	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 3	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 4	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
				48 m			

Table 3.11 Treatments of cassava planting method trial at the Samlout site for 2 year.

Trt	Main plot	Sub plot
M1S1	conventional-hill	horizontal
M1S2	conventional-hill	vertical
M2S1	conventional-flat	horizontal
M2S2	conventional-flat	vertical
M3S1	no till-flat	horizontal
M3S2	no till-flat	vertical

Table 3.12 Plot plan of cassava planting method trial at the Pailin site in 2017-18.

	Conventional hilled		**Conventional flat**		**No Till flat**		
Rep 1	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 2	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	40 m
Rep 3	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 4	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
			48 m				

Table 3.13 Treatment of cassava planting method trial at the Pailin site in 2017-18.

Trt	Main plot	Sub plot
M1S1	conventional-hill	horizontal
M1S2	conventional-hill	vertical
M2S1	conventional-flat	horizontal
M2S2	conventional-flat	vertical
M3S1	no till-flat	horizontal
M3S2	no till-flat	vertical

Table 3.14 Plot plan of cassava planting method trial at the Pailin site in 2018-19.

	Conventional hilled		**Conventional flat**		**No Till flat**		
Rep 1	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 2	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	40 m
Rep 3	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
Rep 4	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	
			48 m				

Table 3.15 Treatment of cassava planting method trial at the Pailin site in 2018-19.

Trt	Main plot	Sub plot
M1S1	conventional-hill	horizontal
M1S2	conventional-hill	vertical
M2S1	conventional-flat	horizontal
M2S2	conventional-flat	vertical
M3S1	no till-flat	horizontal
M3S2	no till-flat	vertical

3.5.2 Chemical fertilizer

Fertilizers for soil application were the combinations of Urea (46-0-0), DAP (18-46-0) and Potassium chloride (0-0-60). Urea was applied at a rate of 50 kg/ha (50 gm/row, 400gm/plot) which equated to 23 kg/ha of N. DAP was applied at a rate of 100 kg/ha (100gm/row, 800gm/plot) which provided 18 kg/ha of N and 20 kg/ha of P (46% P_20_5). N and P fertilizer were applied in a line next to planting row at planting time.

Further to this K and N were applied as 2 split applications of K 50 kg/ha (50gm/row, 400gm/plot) at 1 and 3 months after sowing. Cassava variety 89 (CMR 89) was cultivated in all experiments under rain-fed production systems.

3.5.3 Land preparation

Land preparation involved initially ploughing the whole field by four wheel tractor as the field had come out of conventional cassava with hills when we leased the site. Then hills were pulled up for the conventional hill treatment only, as no requirement to hill up for minimum till and no till treatment. In the second year, only the conventional hill and convention flat treatments were ploughed. No-till was not mechanically disturbed, only sprayed for weed control.

3.5.4 Planting material

Selection of good planting material was an important consideration for the experiment. Initially, cassava stakes were chosen from the same fields, which were the same age and variety. The stems selected had been grown for 10-12 months, had healthy stems, with no sign of disease or insect damage.

3.5.5 Planting method

There were two different planting methods as treatments in this research. Planting method 1 was vertical planting where were planted upright into the soil. Planting method 2 was horizontal planting where were planted horizontally in the soil. Horizontal and vertical planting methods were the split plot treatment applied under the main plots of land preparation. Row spacing for all treatments was 1 m, and a plant spacing of 1 m, resulting in a target population of 10,000 plants per hectare.

3.5.6 Weed control

As with any crop, cassava weed management for the first 1-3 months after planting is critical. Cassava is subject to competition for light, water and nutrients. The weed operation should begin 15-30 days after planting and continue until a canopy has formed. In these experiments, hand weeding was done 3-4 times throughout the crop cycle.

3.5.7 Insect pests and diseases on cassava

Insect pests and diseases found in the trials included low levels of Bacterial Blight disease, Brown Leaf Spot, which occurred as a black spot on the leaves when raining and high humidity. Cassava Witches Broom disease and some rotten plants were present in the trials that appeared to effect cassava yield. No CMD was found in any of the trials. Insect pests such as red spider mites and some mealy bugs were present during hot, dry weather periods.

3.5.8 Harvesting

Harvest was done at 10 months after planting by hand-pulling, aided by lifters, which is the most common farmer practice method. Shovels and a crowbar were used for digging tubers broken off underground to ensure all yield was captured.

3.5.9 Data collection

In both experiments, the plant and biomass data was collected at harvesting. The outside buffer rows were excluded from each plot, with only the plants remaining in the internal 6 rows counted and harvested for yield. Subsequently five subsample plants on the right hand side of the plot and another five plants on the left hand side were used for detailed data measurement of plant components.

The following measurements were taken:

(1) Plant count: Cassava plant counts were recorded at harvest time with the actual plant number of all harvested area (6 rows) counted per plot. Harvested area was 60 m^2 (plant counts were converted to plant population per hectare), with a row spacing of 1 x 1 m and the target plant population was 10,000 plants/ha.

(2) Starch content, 5 kg of fresh root per plot was measured for starch content using commercial silo equipment.

(3) Plant height (cm): 6 plants per plot were measured, from crown of the plant level to the top of plant, using a tape measure.

(4) Above ground biomass (kg/plant): the cassava plant was cut at ground level; fresh leaves and stem were weighed in the field using electronic hanging scale.

(5) Tuber weight in air (kg/plant): the tuber was cleaned, put in the mesh bag and weighed in air.

(6) Tuber weight in water (kg/plant): after tuber weight in air, it was put in water blue bucket for measurement of the starch (%) in water.

(7) The number of tubers/plant was counted and recorded. Five plants designated subsample A and others 5 plants for subsample B in each plot were taken. Numbers of tubers were counted with 4 plants and number of tuber of single plant of each subsample A and Subsample B was counted. Mean number of tuber per plant was equal sum of number of tuber of single plant and numbers tuber of 4 plants of each of each subsample divided by 10.

(8) Fresh weight: 4 plants above ground biomass and tubers was weighed and recorded.

(9) Soil bulk density: Soil bulk density (g/cm^3) and volumetric moisture (m^3/m^3) was determined for each plot. The measurement of soil bulk density was obtained as a key factor to look at correlation of soil compaction with difference farming practices such as conventional hill, conventional flat and no till. The core method (ring method) was conducted in this research. Ring height of 4.7 cm and diameter of 7.5 cm were used for soil sampling in each plot from the trial site. Wet soil samples were weighed in the field and weighed again before oven dried for 24 hours. Bulk density (g/cm2 = net weight dry soil (g) divided by volume of ring, Gravimetric moisture = soil wet weight (g) minus bulk density sample dry weight, and Volumetric moisture (m3/m3) = Bulk density g/cm2 multiply gravimetric moisture.

(10) Soil moisture measurement: Soil moisture measurement was conducted three times; at planting, mid growing season and harvest time for each plot. A

volumetric soil moisture meter (volumetric model: PMS-714) was used for soil moisture measurement in the field.

(11) Cassava gross margin returns were constructed from the operational costs incurred in the trials each season and mean tuber yield for each treatment. Operational costs were converted from the smaller trial area to costs per hectare for easy of comparison.

3.5.10 Data analysis

Data was analyzed using Statistix9 programme and Microsoft Excel with analysis involving General Linear Models (GLM). In all analyses, mean values were compared using Tukey's multiple range tests and the significant differences were tested at P-value < 0.05.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Results of time of planting trials

4.1.1 Effects of time of planting on cassava yield at the Samlout site in 2017-18

This trial was conducted over two years, with three different months of planting (April, May, and June) combined with land preparation treatments of ploughing and conventional hilled up (farmer practice), which was compared with no till planting. Results at the Samlout site in 2017-18 season found that (Figure 4.1), a conventional hill practice planted in May and both treatments planted in June, produced significantly higher yields (34.86 to 38.53 t/ha) than either practice in April (16.41 to 23.94 t/ha, $P<0.05$). However, both conventional hill and no till practice planted in April, did not yield significantly different to the no till treatment planted in May ($P>0.05$). Cassava was planted on 8 April 2017, when the soil was hard and dry (soil moisture ranged from 11.6-12.0%) due to lack of early season rainfall, which made it difficult to plant cassava for all treatments. Consequently, plant survival was low, which also resulted in low yields. Subsequent treatments of cassava planted on 15 May and 6 June 2017, had good soil which ranged from 26.0 to 30.2% at planting time, as opposed to the April planting time which was constrained by low soil moisture.

4.1.1.1 Soil moisture measurement

Soil moisture measurement was conducted three times; at planting, mid growing season and harvest time for each plot. This provided information about

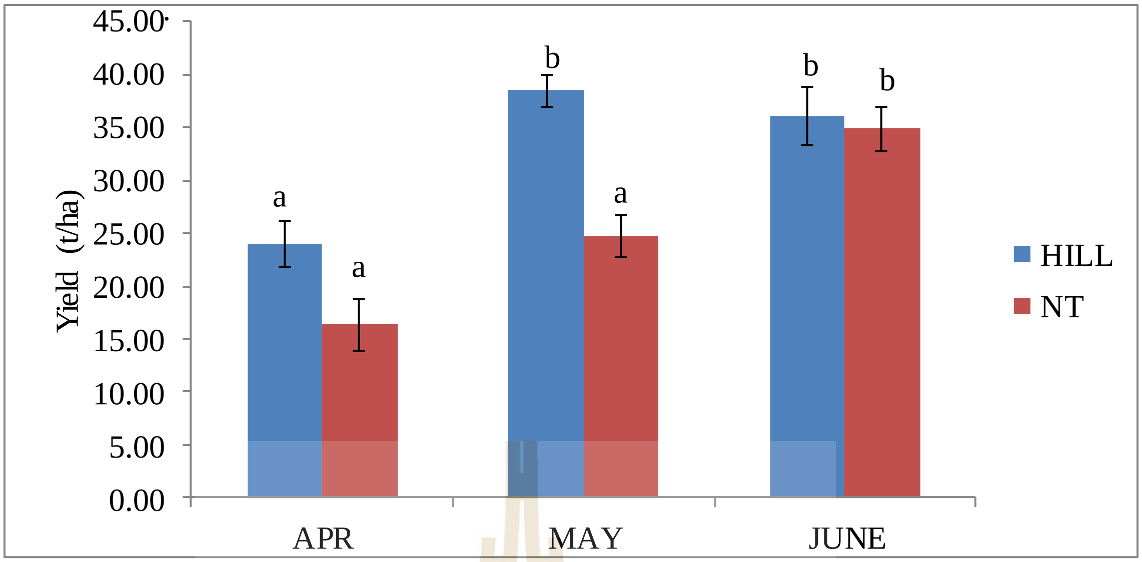

Figure 4.1 Effects of time of planting on cassava yield at the Samlout site in 2017-18. Superscript letters indicate significant differences for yield at $P<0.05$.

soil moisture at key development stages to determine if outcomes (ie plant establishment and yield) were affected by soil moisture during these key periods. At the Samlout site 2017-18, the soil moisture levels at planting time, for both conventional hill and no till farming practice planted in May and June, were significantly higher (27.4 to 31.8%) than either farming practice planted in April (11.6 to 12.0%) (Table 4.1). Soil moisture was less important at the other two measurement times, with no significant differences at mid growing season and harvest. At mid growing season, the soil moisture was highest for all treatments with a range of 28.4 to 34.6%; but was drier at harvest time with a moisture range of 10.2 to 13.8%.

Table 4.1 Volumetric soil moisture readings throughout the growing season, at the Samlout site in 2017-18.

Practice	**Soil moisture reading (%)**		
	Planting time	**Mid growing season**	**Harvest time**
April hill	12.0[b]	30.1	10.8
April NT	11.6[b]	29.6	10.2
May hill	27.4[a]	29.1	13.8
May NT	31.8[a]	34.6	12.4
June hill	30.3[a]	28.4	11.1
June NT	31.3[a]	31.5	12.3

Superscript letters within the same columm indicate significant differences for soil moisture at P<0.05.

4.1.1.2 Cassava plant components at the Samlout site in 2017-18

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.2). At the Samlout site in 2017-18 season, there was no significant difference of plant density, starch content and plant height for any of the treatments ($P>0.05$). The heaviest plant and tuber weights as well as the highest number of tubers per plant were achieved in the June planted treatments and the May hilled up treatment, which were significantly higher than May no till and April planted treatments ($P<0.05$).

Table 4.2 Cassava plant components measured at the Samlout site in 2017-18.

Components	April hill	April NT	May hill	May NT	June hill	June NT
Plant density (plant/ha)	8,208^{a}	7,958^{a}	9,958^{a}	8,833^{a}	9,458^{a}	9,333^{a}
Starch content (%)	24.1	24.0	23.6	23.4	23.2	22.1
Plant height (cm)	135.1	131.5	148.2	121.2	144.1	134.9
Number tuber/plant	7.0^{ab}	4.0^{b}	11.0	8.0^{ab}	9.0	9.0
Plant fresh weight (kg)	3.2^{ab}	2.3^{b}	4.8	3.6^{ab}	5.0	4.6
Tuber fresh weight (kg)	2.1^{ab}	1.2^{b}	3.3	2.5^{ab}	3.4	2.9

Superscript letters within the same columm indicate significant differences for cassava plant components at P<0.05.

4.1.1.3 Production costs and gross margin

Cassava gross margin returns were constructed from the operational costs incurred in the trials each season and mean tuber yield for each treatment (Table 4.3). Operational costs were converted from the smaller trial area to costs per hectare for easy of comparison. At the Samlout site in the 2017-18 season, both conventional hill and no till practice planted in May and June, produced significantly higher returns than either practice in April (P<0.05). Conventional hill planted in May provided a more profitable return of $USD 1,247/ha than no till practice planted in May of $USD 961/ha. Both treatments planted in June provided positive returns of $USD 1,014 /ha and $USD 1,047/ha respectively (Table 4.3). Both conventional hill and no till practice planted in April provided negative returns of -$USD 510/ha and -$USD 779/ha respectively. This was due to low tuber yield, and high costs of weed control and planting materials.

Table 4.3 Production costs and gross margin return at the Samlout site in 2017-18.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 120.00	$ 120.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 853.00
Farming practice	Gross margin ($USD/ha)		
	April	May	June
Hill	-$510	$1,247	$1,047
NT	-$779	$961	$1,014

4.1.2 Effects of time of planting on cassava yield at the Samlout site in 2018-19

At the same site in 2018-19 season, results found that all the conventional hilled treatments regardless of planting month, along with the no till May treatment, produced significantly higher yields (27.35 t/ha, 29.15 t/ha and 31.32 t/ha respectively) than the no till treatment planted in April (14.12 t/ha, P<0.05). However, there was no significant difference between conventional hill planted in April (23.33 t/ha) and to the no till treatment planted in June (19.36 t/ha, P>0.05).

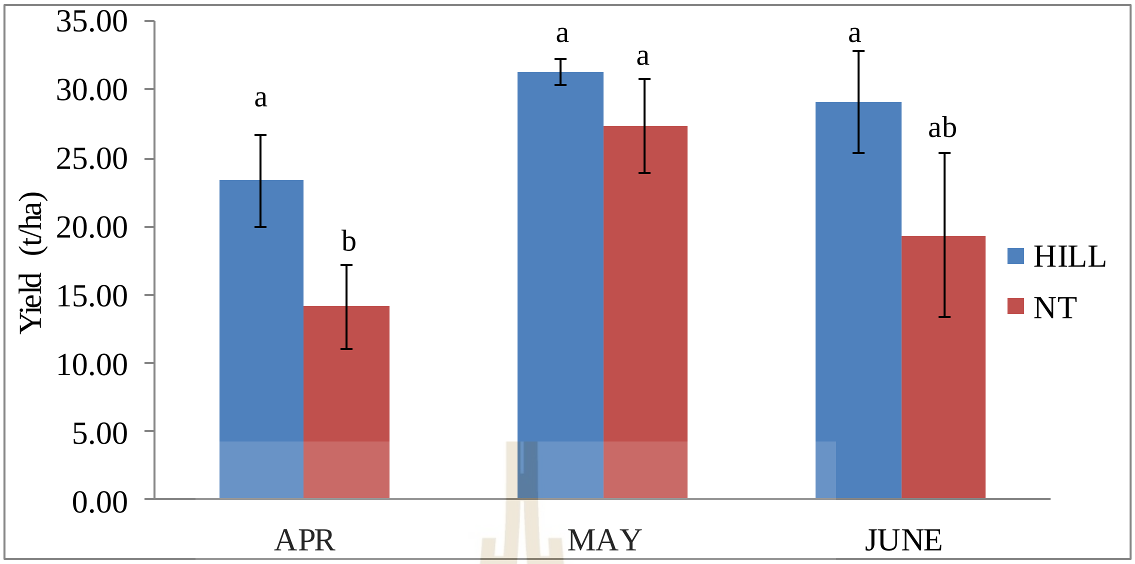

Figure 4.2 Effects of time of planting on cassava yield at the Samlout site in 2018-19 season. Superscript letters indicate significant differences for yield at P<0.05.

4.1.2.1 Soil moisture measurement

In the 2018-19 season soil moisture measurements found that, the soil moisture levels at planting time, for both conventional hill and no till farming practice planted in May and June, were significantly higher (29.6 to 33.9%) than either farming practice planted in April (9.1 to 11.8%) (Table 4.4). Soil moisture was less important at the other two measurement times, with no significant differences at mid growing season and harvest. At mid growing season, the soil moisture was more even across all treatments with a narrower range of 28.4 to 33.7%; and even more so at harvest time with dry soil ranging from 10.1 to 12.4%. These results mirrored those of the first season, demonstrating that soil moisture is critical at planting time and is a useful tool for farmers and advisors to make decisions surrounding time of planting.

Table 4.4 Volumetric soil moisture readings throughout the growing season, at the Samlout site in 2018-19.

Practice	Soil moisture reading (%)		
	Planting time	Mid growing season	Harvest time
April hill	9.1[b]	29.2	10.2
April NT	11.8[b]	29.6	10.2
May hill	29.6[a]	29.1	11.8
May NT	30.3[a]	31.6	12.4
June hill	31.3[a]	28.4	10.1
June NT	33.9[a]	33.7	12.3

Superscript letters within the same columm indicate significant differences for soil moisture at P<0.05.

4.1.2.2 Cassava plant components at the Samlout site in 2018-19

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.5). At the same site in 2018-19 season found that, a conventional hill planted in April produced higher significantly plant density than no till treatment planted in June (P<0.05). The heaviest tuber weights as well as the highest number of tubers per plant were achieved in the May and June planted treatments, which were significantly higher than April planted treatments (P<0.05). There was no significant difference of starch content, plant height, and plant fresh weight for any of the treatments (P>0.05).

Table 4.5 Cassava plant components at the Samlout site in 2018-19.

Components	April hill	April NT	May hill	May NT	June hill	June NT
Plant density (plant/ha)	10,014[a]	10,014[ab]	9,625[ab]	9,250[ab]	7,042[ab]	6,000[b]
Starch content (%)	17.7[a]	19.3[a]	19.4[a]	19.9[a]	19.9[a]	19.8[a]
Plant height (cm)	132.75[a]	121.13[a]	131.13[a]	104[a]	149.4[a]	154[a]
Number tuber/plant	8.0[bc]	6.0[c]	12.0[a]	11.0[ab]	8.0[bc]	9.0[abc]
Plant fresh weight (kg)	3.9[a]	3.8[a]	3.2[a]	4.1[a]	3.0[a]	2.9[a]
Tuber fresh weight (kg)	2.3[bc]	1.5[c]	3.8[ab]	2.8[abc]	4.1[a]	3.9[ab]

Superscript letters within the same columm indicate significant differences for cassava plant components at P<0.05.

4.1.2.3 Production costs and gross margin

At the Samlout in the 2018-19 season found that, all treatments provided negative returns for any of the treatments due to high costs of production including planting material and high costs for weed control. Both treatments planted in April provided negative returns of -$USD792 /ha and -$USD907/ha, both treatments planted in May provided negative returns of -$USD311/ha and -$USD431/ha, and the both treatments planted in June provided negative returns of -$USD667/ha and -$USD882 /ha, respectively.

Table 4.6 Production costs and gross margin return at the Samlout site in 2018-19.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 120.00	$ 120.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 853.00
Farming practice	Gross margin ($USD/ha)		
	April	May	June
Hill	-$907	-$431	-$882
NT	-$792	-$311	-$667

4.1.3 Effects of time of planting on cassava yield at the Pailin site in 2017-18

Results at the Pailin site in 2017-18 season found that, there was no significant differences or interaction in yields between any of the treatments (Figure 4.3, P>0.05), which is in contrast to the results achieved at the Samlout site. Aside from different months of planting, the other significant factors that affected cassava yield were plant density and soil moisture during the growing season, which was also related to humidity, day temperatures and rainfall.

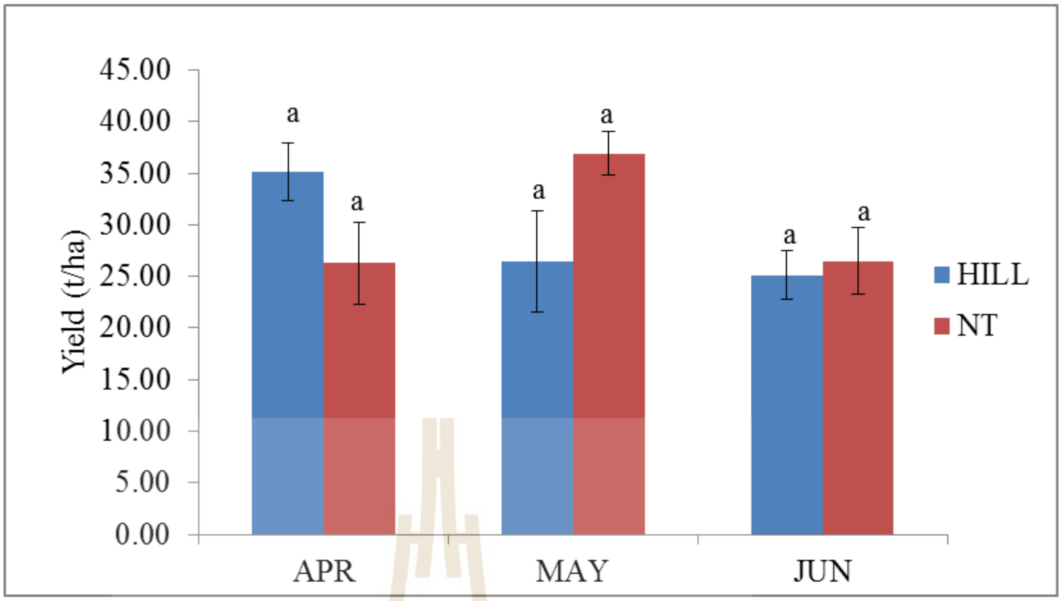

Figure 4.3 Effects of time of planting on cassava yield at the Pailin site in 2017-18. Superscript letter indicate significant difference yield at P<0.05.

4.1.3.1 Soil moisture measurement

At the Pailin site in 2017-18, soil moisture measurement was conducted three times, at planting, mid growing season and harvest time for each plot. At the Pailin site, the soil moisture levels at planting time, for both conventional hill and no till farming practice planted in May and June, were significantly higher (26.7 to 30.2%) than either farming practice planted in April (9.4 to 11.6%) (Table 4.7). Soil moisture was less important at the other two measurement times, with no significant differences at mid growing season and harvest. At mid growing season, the soil moisture was more even across all treatments with a narrower range of 21.4 to 34.3%; and even more so at harvest time with dry soil ranging from 10.0 to 13.7%.

Table 4.7 Volumetric soil moisture readings throughout the growing season.

Practice	Soil moisture reading (%)		
	Planting time	**Mid growing season**	**Harvest time**
Apr hill	9.4^{b}	29.6	12.0
Apr NT	11.6^{b}	29.2	13.7
May hill	26.7^{a}	26.9	29.7
May NT	27.9^{a}	34.3	31.4
Jun hill	30.2^{a}	32.1	13.3
Jun NT	29.9^{a}	21.4	29.0

Superscript letters within the same columm indicate significant differences for soil moisture at P<0.05.

4.1.3.2 Cassava plant components at the Pailin site in 2017-18

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.8). The results at the Pailin site in 2017-18 season showed that the highest plant heights were achieved in the May treatments, which were significantly higher than June planted treatments (P<0.05). The heaviest tuber weights were achieved in the June planted treatments, which were significantly higher than April planted treatments (P<0.05); however statistical significance demonstrated varying levels of difference between treatments. There was no significant difference of starch content, number of tuber per plant, plant fresh weight for any of the treatments (P>0.05).

Table 4.8 Cassava plant components at the Pailin site in 2017-18.

Components	**April hill**	**April NT**	**May hill**	**May NT**	**June hill**	**June NT**
Plant density (plant/ha)	9,458[a]	9,625[a]	9,208[a]	9,583[a]	9,666[a]	9,583[a]
Starch content (%)	24.1[a]	24.0[a]	22.1[a]	22.5[a]	23.4[a]	23.9[a]
Plant height (cm)	160[ab]	153.3[ab]	159.4[ab]	191[a]	122.7[b]	119.5[b]
Number tuber/plant	9.0[a]	6.0[a]	7.0[a]	9.0[a]	7.0[a]	6.0[a]
Plant fresh weight (kg)	4.8[a]	3.0[a]	4.5[a]	5.1[a]	2.9[a]	3.2[a]
Tuber fresh weight (kg)	2.3[bc]	1.5[c]	3.8[ab]	2.7[abc]	4.2[a]	4.0[ab]

Superscript letters within the same columm indicate significant differences for cassava plant components at $P<0.05$.

4.1.3.3 Production costs and gross margin

At the Pailin site in 2017-18 season found that, both conventional hill and no till practice planted in May and June provided more profitable return than either practice planted in April. Both conventional hill and no till planted in April provided in positive returns of $USD101/ha and $USD21/ha, both treatments planted in May provided in positive returns of $USD792/ha and $USD1, 457/ha, and both treatments planted June provided in positive returns of $USD347/ha and $USD398/ha.

Table 4.9 Production costs and gross margin return at the Pailin site in 2017-18.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 120.00	$ 120.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 853.00
Farming practice	Gross margin ($USD/ha)		
	April	May	June
Hill	$101	$792	$347
NT	$21	$1,457	$398

4.1.4 Effects of time of planting on cassava yield at the Pailin site in 2018-19

At the Pailin site in 2018-19 season found that, both conventional hill and no till practices planted in April and May produced significantly higher yields than either practice planted in June (Figure 4.4, $P<0.05$). Both conventional hill and no till plant in April produced yields from 24.33 t/ha to 26.16 t/ha, whilst both treatments planted in May produced yields from 21.25 to 21.37 t/ha, respectively. This was contrast to the both treatments planted in June which produced yields from 6.22 t/ha to 8.75 t/ha, respectively. Cassava planted in June was appear in the lowest yield due to low target plant population (10,000 plant/ha) and low vigour of the planting stakes as they had to be stored 2-3 months before planting, which finally resulted to lowest yield when planted in June.

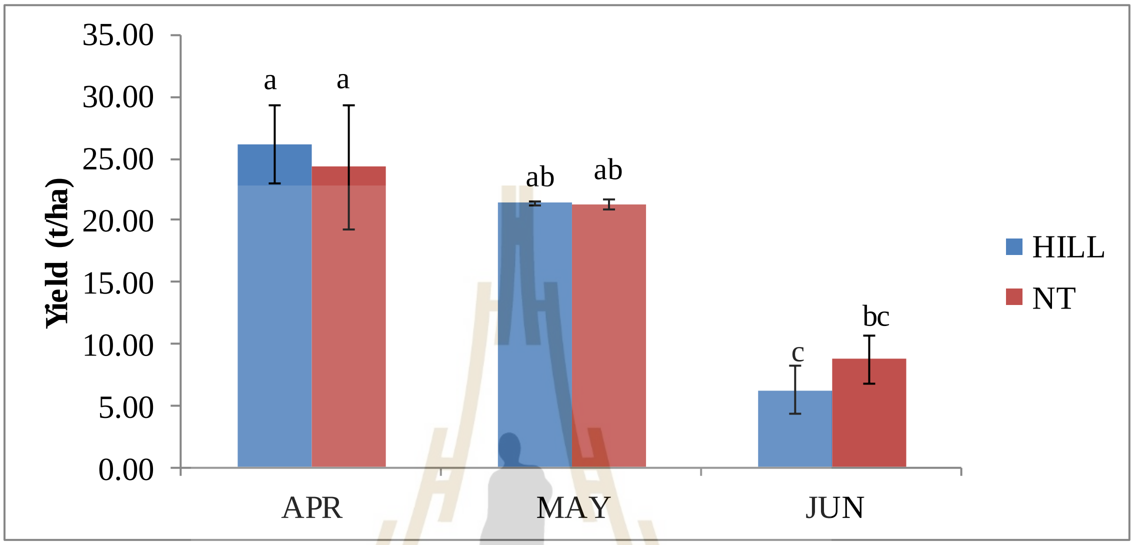

Figure 4.4 Effects of time of planting on cassava yield at the Pailin site in 2018-19. Superscript letters indicate significant difference at $P<0.05$.

4.1.4.1 Soil moisture measurement

At the Pailin site in 2018-19, soil moisture measurement was conducted three times, at planting, mid growing season and harvest time for each plot. The soil moisture levels at planting time, for both conventional hill and no till farming practice planted in May and June, were significantly higher (25.8 to 27.4%) than either farming practice planted in April (10.1 to 10.4%) (Table 4.10). Soil moisture was less important at the other two measurement times, with no significant differences at mid growing season and harvest. At mid growing season, the soil moisture was more even across all treatments with a narrower range of 26.4 to 33.6%; and even more so at harvest time with dry soil ranging from 10.1 to 13.4%.

Table 4.10 Volumetric soil moisture readings throughout the growing season.

Practice	Soil moisture reading (%)		
	Planting time	**Mid growing season**	**Harvest time**
April hill	10.1^{b}	29.6	12.1
April NT	10.4^{b}	29.3	10.1
May hill	27.4^{a}	33.4	12.2
May NT	25.8^{a}	33.6	13.4
June hill	26.5^{a}	26.4	11.5
June NT	26.9^{a}	26.4	13.4

Superscript letters within the same columm indicate significant differences for soil moisture at P<0.05.

4.1.4.2 Cassava plant components at the Pailin site in 2018-19

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.11). The results showed that, the highest plant density as well as number tuber per plant were achieved in the April and May treatments, which were significantly higher than June planted treatments (P<0.05). There was no significant differences of starch content, plant height, and plant fresh weight of any the treatments (P>0.05).

Table 4.11 Cassava plant components at the Pailin site in 2018-19.

Components	April hill	April NT	May hill	May NT	June hill	June NT
Plant density (plant/ha)	10,012[a]	10,012[a]	8,854[a]	8,229[a]	3,125[b]	3,281[b]
Starch content (%)	23.7[a]	22.8[a]	21.3[a]	21.2[a]	20.9[a]	21.5[a]
Plant height (cm)	142.9[a]	144.6[a]	130[a]	191[a]	123.4[a]	120.5[a]
Number tuber/plant	7.0[ab]	7.0[ab]	7.0[ab]	8.0[a]	6.0[ab]	4.0[b]
Plant fresh weight (kg)	4.0[a]	3.8[a]	3.3[a]	4.1[a]	3.0[a]	2.9[a]
Tuber fresh weight (kg)	3.3[a]	2.9[a]	2.7[a]	3.3[a]	2.1[a]	1.8[a]

Superscript letters within the same columm indicate significant differences for cassava plant components at P<0.05.

4.1.4.3 Production costs and gross margin

At the Pailin site in 2018-19 season found that, all treatments provided in negative returns (Table 4.12) due to high costs of production including planting material, high costs for weed control. Both conventional hill and no till planted in April provided in negative returns of -$USD427/ha and -$USD761/ha, both treatments planted in May provided in negative returns of -$USD448/ha and -$USD826/ha, and both treatments planted June provided in negative returns of -$USD984/ha and -$USD1, 106 /ha, respectively.

Table 4.12 Production costs and gross margin return at the Pailin site in 2018-19.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 120.00	$ 120.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 853.00
Farming practice	Gross margin ($USD/ha)		
	April	May	June
Hill	-$761	-$826	-$1,106
NT	-$427	-$448	-$984

4.2 Results of cassava planting method trials

4.2.1 Results of planting methods on cassava yield at the Samlout site in 2017-18

Results at the Samlout site in the 2017-18 season showed that, a conventional hill horizontal and vertical planting method produced yield significantly higher than both conventional flat and no till horizontal and vertical planting method ($P<0.05$) (Figure 4.5). Conventional hill horizontal produced yields of 20.32 t/ha and vertical produced yields 19.21 t/ha, whilst conventional flat and no till horizontal and vertical produced yields from 5.43 t/ha to 7.52 t/ha respectively. The low yields in the conventional flat and no till treatments planting method were confounded by spray drift herbicide damage to the cassava stems and leaves from a nearby field in the first year. There was also water logging and root rot in some plots across the trial.

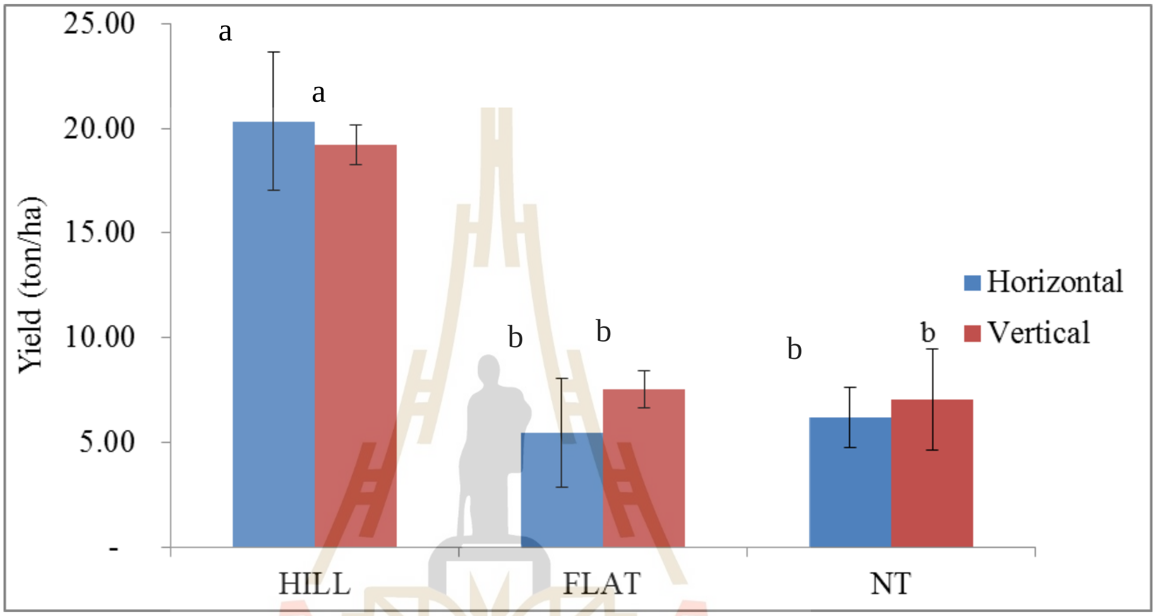

Figure 4.5 Effects of planting methods on cassava yield at the Samlout site in 2017-18 season. Superscript letters indicate significant difference yield at P<0.05.

4.2.1.1 Soil moisture measurement

At the Samlout site in 2017-18, soil moisture measurement was conducted three times, at planting, mid growing season and harvest time for each plot. At the Samlout site in 2017-18 season, results of soil moisture measurement observed that there were no significant differences for any of the treatments at any of the measurement times (P>0.05).

Table 4.13 Volumetric soil moisture readings throughout the growing season.

Practice	Soil moisture reading (%)		
	Planting time	**Mid growing season**	**Harvest time**
Hill horizontal	29.6[a]	30.0	20.3
Hill vertical	29.2[a]	36.0	19.9
Flat horizontal	25.9[a]	37.3	12.9
Flat vertical	34.3[a]	35.9	21.2
NT horizontal	29.1[a]	32.2	22.7
NT vertical	24.3[a]	31.3	24.9

Superscript letter within the same column indicate significant differences for soil moisture at $P<0.05$.

4.2.1.2 Cassava plant components at the Samlout site in 2017-18

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.14). At the Samlout site in 2017-18 season found that, the highest number of tuber per plant as well as heaviest tuber fresh weight were achieved in the conventional hill treatments, which were significantly higher than flat and no till treatments ($P<0.05$). There was no significant differences of, plant density, starch content, and plant height of any the treatments ($P>0.05$).

Table 4.14 Cassava plant components at the Samlout site in 2017-18.

Components	Hill horizontal	Hill vertical	Flat horizontal	Flat vertical	NT horizontal	NT vertical
Plant density (plant/ha)	$9,458^{a}$	$9,625^{a}$	$9,208^{a}$	$9,583^{a}$	$9,666^{a}$	$9,583^{a}$
Starch content (%)	23.3^{a}	23.9^{a}	23.7^{a}	23.4^{a}	23.7^{a}	23.4^{a}
Plant height (cm)	147^{a}	104^{a}	119^{a}	129^{a}	131^{a}	110^{a}
Number tuber/plant	6.0^{a}	6.0^{a}	3.0^{b}	4.0^{ab}	3.0^{b}	4.0^{ab}
Plant fresh weight (kg)	2.6^{a}	3.2^{a}	1.3^{a}	1.9^{a}	1.3^{a}	1.6^{a}
Tuber fresh weight (kg)	2.0^{a}	2.0^{a}	0.7^{ab}	1.01^{ab}	0.6^{b}	1.01^{ab}

Superscript letters within the same column indicate significant differences for cassava plant components at $P<0.05$.

4.2.1.3 Production costs and gross margin

At the Samlout site in 2017-18 season, conventional hill horizontal and vertical provided in positive gross margin return range from $USD8 /ha to $USD247/ha, whilst conventional flat of either planting methods provided in negative return range from -$USD534.50/ha to -$USD716.00 /ha. No till treatments of either planting methods provided negative return range from -$USD573/ha to -$USD584 /ha, respectively (Table 4.15).

Table 4.15 Production costs and gross margin return at the Samlout site in 2017-18.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 60.00	$ 60.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 793.00
Farming practice	Gross margin ($USD/ha)		
	Conventional hill	Flat	NT
Horizontal	$8	-$716	-$584
Vertical	$247	-$534	-$573

4.2.2 Results of planting methods on cassava yield at the Samlout site in 2018-19

The results at the same Samlout site in 2018-19 season (Figure 4.6) showed that the conventional hill with vertical planting method produced yields of 20.4 t/ha which was significantly higher than both no till horizontal at 7.9 t/ha and vertical at 4.6 t/ha planting method ($P<0.05$). However, conventional hill horizontal, did not yield significantly different to the conventional flat horizontal and vertical planting method ($P>0.05$).

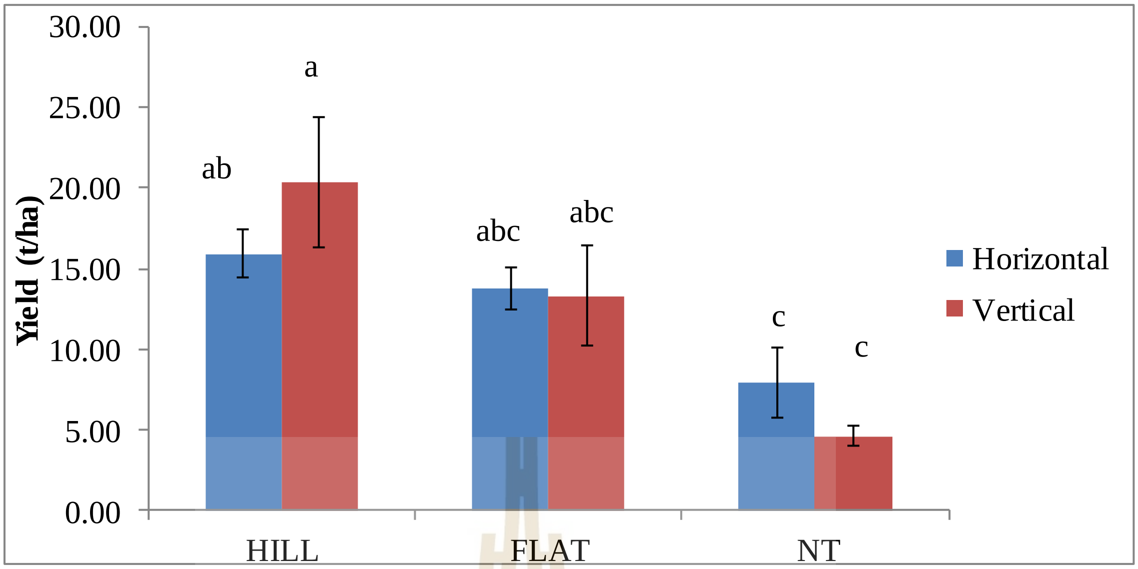

Figure 4.6 Effects of planting methods on cassava yield at the Samlout site in 2018-19 season. Superscript letter indicate significant difference yield at P<0.05.

4.2.2.1 Soil moisture measurement

At the Samlout site in 2018-19 season, results of soil moisture measurement observed that there was no significant differences for any of the treatments at any of the measurement times (P>0.05).

Table 4.16 Volumetric soil moisture readings throughout the growing season, Samlout site in 2018-19.

Practice	Soil moisture reading (%)		
	Planting time	Mid growing season	Harvest time
Hill horizontal	30.1[a]	32.6	24.4
Hill vertical	32.3[a]	30.3	30.2
Flat horizontal	30.0[a]	28.6	22.9
Flat vertical	30.7[a]	31.3	31.6
NT horizontal	29.1[a]	26.0	31.3
NT vertical	30.7[a]	30.0	30.5

Superscript letter within the same column indicate significant differences for soil moisture at $P<0.05$.

4.2.2.2 Cassava plant components at the Samlout site in 2018-19

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.17). At the Samlout site in 2018-19 season, there was no significant difference between any of the treatments for any of the plant components measured ($P>0.05$).

Table 4.17 Cassava plant components at the Samlout site in 2018-19.

Components	Hill horizontal	Hill vertical	Flat horizontal	Flat vertical	NT horizontal	NT vertical
Plant density(plant/ha)	4,474[a]	6,083[a]	5,708[a]	4,250[a]	5,208[a]	3,441[a]
Starch content (%)	20.3	20.4	20.1	19.6	19.7	18.8
Plant height (cm)	109.5	113.5	143.5	116.9	122.4	99.4
Number tuber/plant	6.0	6.0	8.0	8.0	9.0	6.0
Plant fresh weight (kg)	4.2	4.4	3.7	3.8	2.8	2.1
Tuber fresh weight (kg)	3.3	3.4	2.8	2.9	2.2	2.6

Superscript letter within the same column indicate significant differences for cassava plant components at $P<0.05$.

4.2.2.3 Production costs and gross margin

At the same Samlout site in 2018-19 season found that, all treatments provided negative returns (Table 4.18) due to low yields, particularly in conventional flat and no till practices of either planting methods, combined with high costs of production including planting material and high costs for weed control. Conventional hill horizontal and vertical provided negative returns range from -$USD796 to -$USD1,139/ha, whilst conventional flat of either planting methods provided in negative return range from -$USD1,098 to -$USD1,205/ha. No till treatments for both vertical and horizontal planting methods produced negative returns ranging from -$USD1, 424 to -$USD1, 514/ha, respectively.

Table 4.18 Production costs and gross margin return at the Samlout site in 2018-19.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 60.00	$ 60.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 793.00
Farming practice	Gross margin ($USD/ha)		
	Conventional hill	Flat	NT
Horizontal	-$1,139	-$1,098	-$1,514
Vertical	-$796	-$1,205	-$1,424

4.2.2.4 Soil bulk density

Results at the Samlout site in 2018-19 season showed that soil bulk density did not correlate to soil compaction and soil moisture with the different farming practices of conventional hill, conventional flat and no till. We would expect to see a difference in bulk density between the no-till treatments and the plough based treatments, with the no-till soil softening over time and the plough based treatments trending to a harder, blockier configuration with loss in structure and organic matter. So, whilst this first assessment is a valuable start, this trial only ran for two years; it would be more appropriate to monitor the soil structural change over a longer period of time. For future research, it would be useful to establish a long term trial site where it would be possible to assess soil characteristics and the changes in soil bulk density of different farming practices over time.

Table 4.19 Soil bulk density at the Samlout site in 2018-19.

Farming practice	Soil bulk density measurement					
	Bulk density (gm/cm^3)		gravimetric moisture		Volumetric moisture (m^3/m^3)	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Conventional hill	0.93[a]	0.97	0.24	0.33	0.22	0.32
Conventional flat	1.04[a]	0.99	0.17	0.19	0.18	0.19
NT	1.04[a]	1.03	0.18	0.15	0.19	0.16

Superscript letter within the same column indicate significant differences soil bulk density at P<0.05.

4.2.3 Results of planting methods on cassava yield at the Pailin site in 2017-18.

Results at the Pailin site in the 2017-18 season showed that, there were no significant differences between yields for any of the treatments (Figure 4.7, P>0.05).

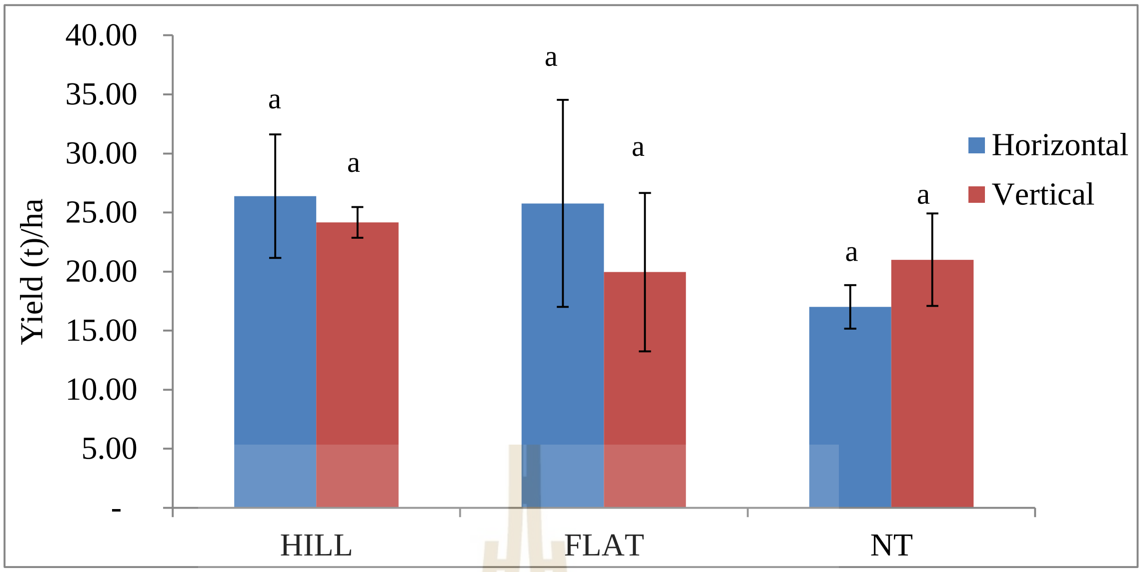

Figure 4.7 Effects of planting methods on cassava yield at the Pailin site in 2017-18. Superscript letter indicate significant difference yield at $P<0.05$.

4.2.3.1 Soil moisture measurement

At the Pailin site in 2017-18, soil moisture measurement was conducted three times, at planting, mid growing season and harvest time for each plot. At the Pailin site in 2017-18, results of soil moisture measurement observed that there was no significant differences for any of the treatments at any of the measurement times ($P>0.05$).

Table 4.20 Volumetric soil moisture readings throughout the growing season.

Practice	Soil moisture reading (%)		
	Planting time	Mid growing season	Harvest time
Hill horizontal	32.4[a]	29.6	28.4
Hill vertical	33.3[a]	30.6	29.2
Flat horizontal	29.0[a]	19.9	28.4
Flat vertical	29.3[a]	22.8	29.6
NT horizontal	29.1[a]	27.9	28.9
NT vertical	30.4[a]	28.7	21.5

Superscript letter within the same column indicate significant differences for soil moisture at $P<0.05$.

4.2.3.2 Cassava plant components at the Pailin site in 2017-18

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.21). At the Pailin site in 2017-18 season found that the highest plant height were achieved in the no till vertical treatment, which were significantly higher than no till horizontal treatment ($P<0.05$). There was no significant difference in plant density, starch content, number of tuber per plan, plant and tuber fresh weight for any of the treatments ($P>0.05$).

Table 4.21 Cassava plant components at the Pailin site in 2017-18.

Components	Hill horizontal	Hill vertical	Flat horizontal	Flat vertical	NT horizontal	NT vertical
Plant density (plant/ha)	8,875[a]	9,625[a]	8,791[a]	8,458[a]	6,833[a]	9,333[a]
Starch content (%)	21.4	19.1	20.3	19.7	19.3	19.8
Plant height (cm)	127.1[ab]	147.5[ab]	167.5[ab]	122[ab]	119.1[b]	170.2[a]
Number tuber/plant	6.0[a]	7.0[a]	7.0[a]	6.0[a]	6.0[a]	6.0[a]
Plant fresh weight (kg)	3.2	3.7	3.9	2.7	2.4	2.6
Tuber fresh weight (kg)	1.6	2.9	3.7	1.9	1.8	2.9

Superscript letters within the same column indicate significant differences for cassava plant components at $P<0.05$.

4.2.3.3 Production costs and gross margin

At the Pailin site in 2017-18 season we found that, conventional hill of horizontal and vertical planting methods provided in the most profitable returns range from USD414 to USD468 /ha, respectively. The conventional flat vertical provided return USD186 /ha which was higher than horizontal which returned USD130 /ha. The no till horizontal and vertical provided returns of USD239 to USD 292 /ha, respectively.

Table 4.22 Production costs and gross margin return at the Pailin site in 2017-18.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 60.00	$ 60.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 793.00
Farming practice	Gross margin ($USD/ha)		
	Conventional hill	Flat	NT
Horizontal	$468	$130	$292
Vertical	$414	$186	$239

4.2.4 Results of planting methods on cassava yield at the Pailin site 2018-19

Results at the Pailin site in 2018-19 season (Figure 4.8) showed that the conventional hill horizontal produced yields significantly higher than the no till horizontal ($P<0.05$). However, there was no yields significantly difference between conventional hill vertical treatment to the conventional flat treatments and no till vertical treatment ($P>0.05$). It was appear that no till treatments produced the lowest yields due to low vigour of the planting stakes, root rot combined with a low target plant population (10,000 plants/ha).

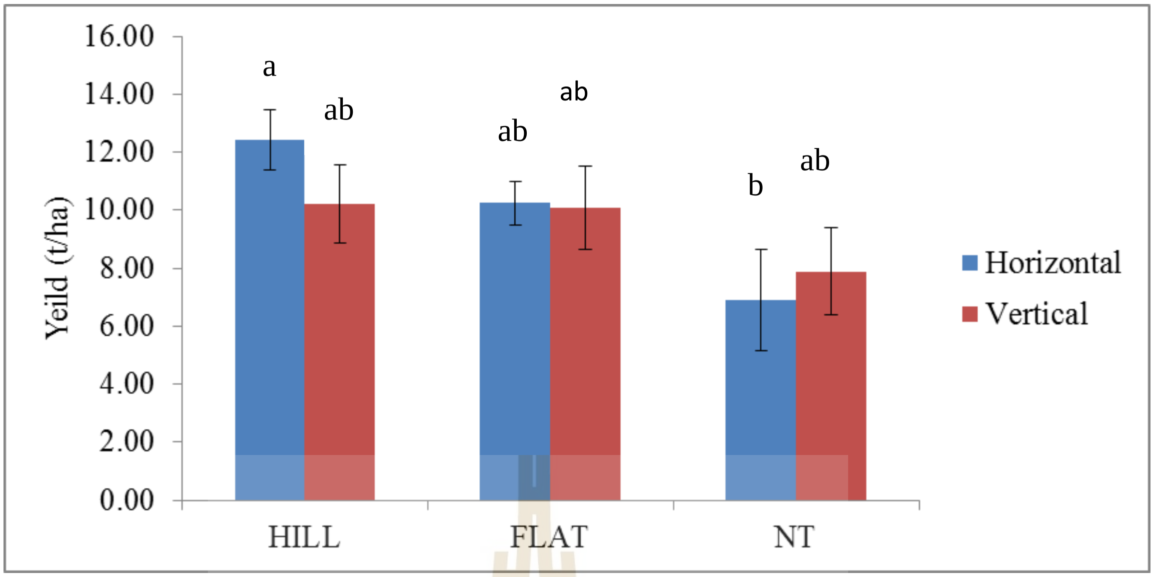

Figure 4.8 Effects of planting methods on cassava yield at the Pailin site in 2018-19. Superscript letters indicate significant difference yield at P<0.05.

4.2.4.1 Soil moisture measurement

At the Pailin site in 2018-19, soil moisture measurement was conducted three times; at planting, mid growing season and harvest time for each plot. Results of soil moisture measurements recorded that there were no significant differences for any of the treatments at any of the measurement times (P>0.05).

Table 4.23 Volumetric soil moisture readings throughout the growing season.

Practice	Soil moisture reading (%)		
	Planting time	**Mid growing season**	**Harvest time**
Hill horizontal	24.0[a]	30.1	19.0[a]
Hill vertical	25.3[a]	30.9	26.6
Flat horizontal	25.3[a]	26.6	29.5
Flat vertical	26.4[a]	33.6	25.8
NT horizontal	28.0[a]	29.7	23.6
NT vertical	28.7[a]	30.3	33.3

Superscript letter within the same column indicate significant differences for soil moisture at $P<0.05$.

4.2.4.2 Cassava plant components at the Pailin site in 2018-19

Plant characteristics including cassava plant density (plant/ha), starch content (%), plant height (cm), number of tuber/plant, plant fresh weight (kg), and tuber fresh weight (kg) was summarized in (Table 4.24). At the second Pailin site in 2018-19 season found that, there was no significant difference any of the treatments for cassava plant components ($P>0.05$).

Table 4.24 Cassava plant components at the Pailin site in 2018-19.

Components	Hill horizontal	Hill vertical	Flat horizontal	Flat vertical	NT horizontal	NT vertical
Plant density(plant/ha)	4,166[a]	3,854[a]	4,114[a]	3,854[a]	4,323[a]	3,3437[a]
Starch content (%)	18.5	19.3	18.2	20.0	19.2	21.6
Plant height (cm)	107.9	121.6	113.5	111.7	109.7	111.2
Number tuber/plant	5.0	6.0	6.0	6.0	5.0	5.0
Plant fresh weight (kg)	2.8	3.5	3.5	3.5	2.7	2.6
Tuber fresh weight (kg)	2.18	2.17	2.40	2.63	2.81	2.8

Superscript letter within the same column indicate significant differences for cassava plant components at P<0.05.

4.2.4.3 Production costs and gross margin

At the Pailin site in 2018-19 season found that, all treatments was provided negative returns due to low yields, below target plant populations (<10,000 plants/ha), in conjunction with high costs of weed control and planting materials.

Table 4.25 Production costs and gross margin return at the Pailin site in 2018-19.

Operation	**Unit**	**Unit cost ($)**	**Total ($)**
Land preparation (ha)	1	$ 60.00	$ 60.00
Cassava planting labour (ha)	1	$ 65.00	$ 65.00
Planting material (bundle)	200	$ 1.50	$ 300.00
Fertilizer (kg)	150	$ 0.60	$ 90.00
Labour application (person)	6	$ 7.00	$ 42.00
Weed control (person)	32	$ 7.00	$ 224.00
Labour to harvest cassava (tons)	1	$ 6.00	$ 6.00
Transport tuber to Silo (tons)	1	$ 6.00	$ 6.00
Total costs			$ 793.00
Farming practice	Gross margin ($USD/ha)		
	Conventional hill	Flat	NT
Horizontal	-$928	-$1,016	-$1,177
Vertical	-$1,036	-$983	-$1,098

4.2.4.4 Soil bulk density

Results at the Pailin site in 2018-19 season, we found that soil bulk density did not correlate to soil compaction and soil moisture with the different farming practices of conventional hill, conventional flat and no till.

Table 4.26 Soil bulk density at the Pailin site in 2018-19.

Farming practice	Soil bulk density measurement					
	Bulk density (gm/cm^3)		gravimetric moisture		Volumetric moisture (m^3/m^3)	
	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
Conventional hill	0.88[a]	0.82	0.29	0.31	0.25	0.26
Conventional flat	0.79 [a]	0.90	0.30	0.29	0.24	0.26
NT	0.85 [a]	0.87	0.26	0.3	0.22	0.27

Superscript letter within the same column indicate significant differences soil bulk density at P<0.05.

4.3 Discussion

4.3.1 Effect of time of planting trials for two years season at Samlout and Pailin site

Our two year study at the Samlout site found that, both conventional hill and no till practices planted in May and June produced higher yields than either practices planted in April. Similar results were achieved in a similar time of planting cassava experiment run over four years at Rayong Field Crops Research Center in the eastern of Thailand (Sinthuprama and Tiraporn, 1987). This study found that the highest root yields of cassava were obtained when planted in the rainy season from June to October; and yields were lowest when cassava was planted from February to April (Sinthuprama and Tiraporn, 1987). The significant effect of planting time on yield at Samlout was explained by the factors of soil moisture and rainfall. Moisture limitation was a major factor at the establishment phase during this experiment. In our trials, cassava planted in April; when the soil was hard and dry, had difficultly establishing and plant survival was lower than the alternative months of May and June, which resulted in the lowest yields from April planting, regardless of land preparation. These results illustrated that soil moisture is critical at planting time and is a useful tool for farmers and advisors to make decisions surrounding time of planting. Soil moisture stress at planting time can be explained by the climate, as April is the hottest month of the year and rainfall is sporadic and often less than 50 mm in total for the month. Rainfall is the critical climatic factor that distinguishes agro ecological zones and also a major factor during the crop establishment phase (Fresco, 1993). At the Samlout site in 2017-18 season, rainfall received in April (29 mm in total for the month) was less than in May and June (146 mm and 235 mm in total for the month), which is typical in Northwest Cambodia. In our trials, cassava planted in April, demonstrated that soil moisture stress during the hottest month of the year, with only sporadic, low rainfall had a significant detrimental effect on both establishment and yield of cassava compared to May and June planting conditions. Our findings concur with other research, including a trial in Nigeria which found that soil moisture stress led to a decline in number of tubers by 95%, tuber yield by 87%, and plant height by 47% (Aina & Akinrinde, 2007). The simple action of delaying planting time by 1-2 months could be easily implemented by farmers in our region and beyond, to successfully mitigate the risk of crop failure, stabilize production and optimize yield. At the Pailin site in 2017-18 season results found that, there were no significant differences or interactions in yields between any of the treatments. These findings can be explained by rainfall during the planting month. At the Pailin site in 2017-18 season, rainfall received in April was 92 mm for the month, in May was 104 mm for the month and in June was 161 mm for the month. The site at Pailin in 2018-19 season, found that all treatments planted in April and May produced significantly higher yield than either practice in June, which is in contrast to the results at the Samlout site. These contrasting findings can be explained by rainfall during the planting month. At the Pailin site in 2018-19 season, rainfall received in April was 82 mm for the month, and in May was 88 mm, which for both months was considerably higher than in June which only received 21 mm in total for the month. The reverse happened at Samlout site in 2018-19 season, where rainfall received in April was only a trace amount of 3 mm in total for the month, compared to the significant establishment rainfall totals of 123 mm and 271 mm in total for the months of May and June respectively. Aside from planting time, the other significant factors that affected cassava yield were plant density and soil moisture during the growing season, which was also related to humidity, daytime temperatures and rainfall. The fact that soil moisture was closely aligned to climate variables was not surprising, however we did hypothesize that there would be significant differences in moisture content between the conventionally ploughed and hilled treatment and no-till treatments. This did not occur and we speculate that this may be due to all treatments being equally constrained by soil moisture at the establishment phase of cassava, especially in the first year of planting as the whole site came out of conventional hilled up cassava the previous season. Perhaps the plant architecture of cassava has some bearing on the establishment of the different treatments. Some of the benefit of no till comes from increased biomass on the soil surface from crop residues, which helps keep more water in the soil profile by increasing infiltration and reducing evaporation, providing better conditions for germination and establishment (Leng Vira et al., 2018). A study on yield responses of maize and sunflower to mulch under no-till farming in Northwest Cambodia found that the highest soil moisture (39%) was recorded in the 20 t/ha of maize stover mulch plots (highest mulch treatment) and that there was minimal moisture in the nil mulch plots (Montgomery et al., 2016). Crop residues often result in a layer of mulch which protects the soil from the impact of rainfall and wind, stabilizes soil moisture and temperature in the surface layers and allows for great water infiltration into the soil and less runoff (Montgomery et al., 2016). This doesn’t seem to happen with cassava as there are very little surface residues after harvest and stems are collected and removed from the field. Research investigating system impacts on cassava yield on sloping land in Northern Vietnam found that there were significant differences in systems of cassava, with grass hedgerows yielding higher than a straight monocropping system (Howeler, 2014). Cassava with grass hedgerows plots provided more stored moisture and reduced water runoff than monocropping system (Howeler, 2014). In our trial at the Pailin site in 2017-18 and in 2018-19, both conventional hill and no till treatments didn't give benefits for any treatments we expected due to high costs of production and high casual labour costs for weed control. Another study on traditional tillage and no-till for cassava production in Southeastern Nigeria supports our findings, as they similarly did not achieve significant differences in cassava yield (Sorrenson et al., 1998). Likewise, a trial on cassava planting systems in a sandy-clay-loam soil at Zaire, Nigeria (Ezumah, 1980), found that yields were not significantly different between hilled up treatments and no-till treatments (yields ranged of 20.4 t/ha to 21.8 t/ha). Other studies investigating time of planting have been conducted in Thailand (Sinthuprama et al., 1983), Indonesia (Wargiono, 2001; Fauzan and Puspitorini, 2001), China (Zhang Weite, 1998) and the Philippines (Villamayor and Daviner, 1987). In general, yields were found to be higher when cassava was planted in the early part of the rainy season (May-June in most countries, October-November in Indonesia) or the early of spring (February-March in North Vietnam and China). In many countries some cassava was also planted at the end of rainy season, such as in August-September in Kerala, India, or in September-November in Thailand and South Vietnam (Sinthuprama et al., 1983). In Hainan island of China, cassava can be planted throughout the year due to high rainfall when harvested 12 months after planting, but only from February to May when harvest at 8 months after planting; starch contents were always highest when the roots were harvested in the dry and cold months of November to March (Zhang Weite *et al.*, 1998). Stakes for planting should be stored in the shed to avoid stem deterioration and loss of vigour before planting. In our trials at the Pailin site in 2018-19 season, stakes stored in sun were destroyed by termites leading to the low germination and low plant density, which was reflected in results producing the lowest yield when cassava was planted in June, which was the longest period of time since previous harvest, so the stakes had to be stored longer. A study on the effect of stake storage methods on germination, growth and yield of cassava was conducted at the Agronomy Field Crop Research Station, Faculty of Agriculture, Khon Kaen University, Thailand. The results found that stems stored in the shed avoided stem deterioration and loss of vigour which resulted in the highest germination and survival percentage, and equated to higher plant density (Promkhambut et al., 2015). We compared the gross margin return both trials site during 2017-18 and 2018-19 showed that, planting cassava in May and June provided positive gross margin return of $USD 792 /ha and $USD 1457 /ha respectively, whilst conventional hill and no till practice planted in April provided negative returns of -$USD 510 /ha and -$USD 779 /ha respectively. In my research over 2 seasons, we demonstrated good yields and increased profitability at the altered time of planting in May and June, which may improve cassava yield and reduce the risk of crop failure in comparision to the results achieved from current planting times.

4.3.2 Effect of cassava planting method for two years at Samlout and Pailin site

Results at the Samlout site consistently found that the conventional hilled up planting method with either vertical or horizontally planted stakes were the highest yielding treatments. Furthermore, the no-till planting method in either stake position was always the lowest yielding treatment, and the conventional flat (minimum till) treatments yielded somewhere in between. The conventional flat and no till treatments were affected by herbicide damage due to spray drift from a nearby field in the first year. However, results from the second year of trials, supported the initial findings. Results at the Pailin site in

2017-18 season found that, there were no significant differences in yield for any treatments. Additionally, results at the Pailin site in 2018-19 season concurred with Samlout site that the conventional hilled treatments yielded significantly higher than the no-till treatments but not statistically different to the conventional flat treatments. A study evaluated the effects of planting methods (vertical and horizontal) on root yield and nutrient removal of five cassava cultivars (Rayong-7, Rayong-11, Rayong-72, Huaybong-80 and E-dum) in Rayong Province, Thailand showed that vertical planting method gave higher root yield (88.8%) than horizontal and inclined planting in sandy clay loam soil (Tongglum et al., 2001).

We compared the gross margin returns from both trial sites during 2017-18 and 2018-19 which showed that, almost all of the treatments provided negative returns due to low yields, high cost of weed control, high cost of labour and low established plant population. However, at the Pailin site in 2017-18 season, conventional hill of horizontal and vertical planting methods provided more profitable returns than conventional flat and no till treatments. This study also measured soil bulk density at all sites, as an indicator of the effect of the different farming practices on soil structure and stability. We found that soil bulk density did not correlate to soil compaction and soil moisture with the different farming practices of conventional hill, conventional flat and no till. We would expect to see a difference in bulk density between the no-till treatments and the plough based treatments, with the no-till soil softening over time and the plough based treatments trending to a harder, blockier configuration with loss in structure and organic matter (Fauzan, 2001). So, whilst this first assessment is a valuable start, this trial only ran for two years; it would be more appropriate to monitor the soil structural change over a longer period of time. For future research, it would be useful to establish a long term trial site where it would be possible to assess soil characteristics and the changes in soil bulk density of different farming practices over time.

CHAPTER V

CONCLUSION

This is the first research to study the effect of time of planting and different cassava planting methods in Northwest Cambodia. Currently upland cropping systems in the region face many challenges including crop failures in the early wet season due to drought, loss in crop diversity, and declining soil fertility. This study was conducted with the objectives of evaluating the effect of time of planting on cassava yield under two different farming practices (conventional hill and no till) and three different months of planting (April, May and June), and also to investigate different planting methods in relation to horizontal versus vertical stem placement along with land preparation methods of conventional hilled, reduced tillage and no tillage in northwest Cambodia. The aims of this study were to gain agronomic knowledge which will help guide the research and extension for improving the production of cassava in Northwest Cambodia. This work serves as a demonstration to farmers in relation to alternative time of planting to reduce the risk of crop failure due to drought and suitable cassava planting method. It is useful to be able to compare farming practices and planting times in small plot replicated trials on farm in their region.

The research was conducted in Battambang and Pailin provinces in Northwest Cambodia which is the largest cassava production area in the region. The objectives were: 1) to determine if it is more feasible and less risky to grow cassava at alternative months of planting compared to usual farmer practice in Northwest Cambodia of planting in Feb/March/April; and within this system compare no till conservation agriculture versus conventional planting on hills. 2) To investigate different planting methods in relation to horizontal versus vertical stem placement along with land preparation methods of conventional hilled, reduced tillage and no tillage.

In corresponding to objective (1); the results of this study for two years demonstrated that cassava planted in April, which is the driest and hottest month in this area, resulted in lower yields than cassava planted in May and June under conventional hill and no till farming practices. Hence, planting cassava in May and June can be used as the basis for recommendations for alternative planting windows for reduction of crop failure and improvements to cassava production in the region. The results demonstrated that, shifting planting times back to cooler months with more reliable rainfall is successful for cassava in Northwest Cambodia.

This research recommends that farmers plant cassava in May and June, when temperatures begin to cool and rainfall is more reliable, with adequate stored soil moisture, in Northwest Cambodia. These results highlight the importance of managing planting time and shifting time of planting in the pre-monsoon period. It is now clear that planting cassava in May is a viable alternative time of planting to obtain high yielding cassava and more profitable gross margin returns. However, selection of good quality, healthy planting stakes is of critical importance to achieving high yields. Stakes for planting should be stored in the shed to avoid stem deterioration and loss of vigour before planting.

In corresponding to objective (2); the results from two year research study indicated that conventional hill horizontal and vertical planting method gave yield significantly higher than those conventional flat and no till horizontal and vertical planting methods. However, in the conventional hill treatment, vertical planting tended to have significantly higher than horizontal planting. It may be not a realistic expectation that farmers in the region will adopt conventional flat and no till farming horizontal and vertical planting method, as there is no yield or profit advantage. Hence, conventional hill vertical planting method can be used as the basis for recommendations for farmers and improvements to cassava production in the region. However, it is recommended that minimum till methods on sloping land are adopted by farmers as soon as possible in the future.

At both sites, our research found that soil bulk density was not significantly correlated with soil compaction and soil moisture between the different farming practices of conventional hill, conventional flat and no till. This first assessment is a valuable indicator, and in future, additional soil assessments should be conducted on the same trial site to assess the changes in soil bulk density over time of different farming practices.

REFERENCES

Aina, O., Dixon, A., & Akinrinde, E. J. P. j. o. b. s. P. (2007). **Effect of soil moisture stress on growth and yield of cassava in Nigeria**. 10(18): 3085-3090.

Bell, R.W., Seng, V., Schoknecht, N., Hin, S., Vance, W. and White, P.F. (2005). **Land Capability Classification for Non-Rice Crops in Soils of the Sandy Terrain of Tram Kak District, Takeo Province**. CARDI Soil and Water Science Technical Note No.9.

Bell, R., Seng, V., Schoknecht, N., Vance, W., & Hin, S. (2007). **Soil Survey of the Province Battambang**, The Kingdom of Cambodia.

De Costa, W., & Sangakkara, U. J. T. J. o. A. S. (2006). **Agronomic regeneration of soil fertility in tropical Asian smallholder uplands for sustainable food production**. 144(2): 111-133.

Diepart, J. C., & Sem, T. J. J. o. A. C. (2018). **Fragmented territories: Incomplete enclosures and agrarian change on the agricultural frontier of Samlaut district**, North-West Cambodia. 18(1): 156-177.

Ezumah, H. C., & Okibo, B. N. (1980). **Cassava planting systems in Africa. In Cassava cultural practices: proceedings of a workshop... Salvador**, Bahia, Brazil, 18-21 March 1980. IDRC, Ottawa, ON, CA.

Fauzan and P. Puspitorini. 2001. **Effect of date of planting and rainfall distribution on the yield of five cassava varieties in Lampung, Indonesia**. In: R.H. Howeler and S.L. Tan (Eds.). Cassava’s Potential in Asia in the 21st Century:

Present Situation and Future Research and Development Needs. Proc. 6th Regional Workshop, held in Ho Chi Minh city, Vietnam. Feb 21-25, 2000.

FAOSTAT, 2011. **Food and Agricultural Commodity Production**. Food and Agriculture Organization of the United Nations. Retrieved 23 July 2011. http://faostat.fao.org/site/339/default.aspx.

Hammer, G. L., Hobman, F. R., & Shepherd, R. K. (1987). **Effects of planting time and harvest age on cassava (Manihot esculenta) in Northern Australia**. I. Crop growth and yield in moist environments. Experimental Agriculture, 23(4), 401-414.

Hershey, C. H., & Howeler, R. H. (2000). **Cassava in Asia: Designing crop research for competitive markets**. Paper presented at the Proc. 6th Regional Workshop, held in Ho Chi Minh City, Vietnam.

Howeler, R. (1995). **Mineral nutrition of cassava**. Paper presented at the Mineral Nutrient Disorders of Root Crops in the Pacific. Proc. Workshop held in Nuku'alofa, Kingdom of Tonga.

Hin, S., N. Schoknecht, W. Vance, R.W. Bell, and V. Seng . 2005. **Soil and landscapes of basaltic terrain in Ou Reang Ov district, Kampong Cham province, Kingdom of Cambodia**. CARDI Soil and Water Science Technical Note No. 3. Cambodian Agricultural Research and Development Institute (CARDI), Phnom Penh, Cambodia.

Hin, S., Schoknecht, N., Vance, W., Bell, R.W. and Seng, V. (2005c). **Soil and Landscapes of Banan District, Battambang Province, Kingdom of Cambodia**. CARDI Soil and Water Science Technical Note No.6.

Howeler, R.H. 1996 b. Mineral nutrition of cassava, In: E.T. Craswell, C.J. Asher, and J.N. O'Syllivan (eds.). **Mineral Nutrient Disorders of Root Crops in the Pacific. Proceedings of the Workshop held in Nuku'alofa, Kingdom of Tongka**. 17-20 April 1995. ACIAR Proceedings no. 65. Canberra, Australia.110-116.

Howeler, R.H. 2000. **Cassava production practices-can they maintain soil productivity.** In: R.H. Howeler, C.G. Oates, and G.M. O'Brien, (eds.). Cassava, Starch and Starch Derivatives. Proceedings of an International Symposium, 11-15 November 1996. Nanning, Guangxi, China. CIAT: Cali, Columbia. 101-117.

Howeler, R.H., and Thai Phien. 2000. **Integrated nutrient management for more sustainable cassava production in Vietnam**. Proceedings of the Vietnamese Cassava Workshop on Progress in Cassava Research and Extension in Vietnam. 16-18 March 1999, Ho Chi Minh city, Vietnam. 12-54.

Howeler, R.H. 2001. **Nutrient input and losses in cassava-based cropping systems-Examples from Vietnam and Thailand**. Proceedings of an International Workshop on Nutrient Balances for Sustainable Agricultural Production and Natural Resource Management in Southeast Asia. 20-22 February 2001, Bangkok, Thailand. 1-30.

Howeler, R.H. 2002. **Cassava mineral nutrition and fertilization**. In: R.J. Hillocks, J.M. Thresh, and A.C. Bellotti, (eds.). Cassava: Biology, Production and Utilization. CABI Publishing, CAB International, Wallingford, UK. 115-147.

Howeler, R. H. (2004a). **Cassava in Asia: present situation and its future potential in agro-industry**.

Howeler, R. H. (2004b). **Nutrient inputs and losses in cassava-based cropping systems: examples from Vietnam and Thailand**.

Howeler, R. (2006). **Cassava in Asia: trends in cassava production, processing and marketing**. In Workshop on "Partnership in modern science to develop a strong cassava commercial sector in Africa and appropriate varieties by. 2-6.

Kem, S. (2017). **Commercialisation of smallholder agriculture in Cambodia: impact of the cassava boom on rural livelihoods and agrarian change**.

MAFF-UNDP, (2015). **Ministry of Agriculture Fisheries and Forestry**. Book of Agricultural Statistics and Research Planning. Department of Planning and International Cooperation, MAFF, Cambodia, (Khmer language).

MAFF, (2018). **Report on Activities of the Ministry of Agriculture, Forestry and Fisheries**. Workshop on National Achievement in 2017-2018 and Planning for 2018-2019. 2-3 April 2018. MAFF, Phnom Penh, Cambodia. (Khmer language).

Montgomery, S. C., Martin, R. J., Guppy, C., Wright, G. C., Flavel, R. J., Phan, S., Tighe, M. K. J. F. C. R. (2016). **Crop choice and planting time for upland crops in Northwest Cambodia**. 198: 290-302.

Montgomery, S., Guppy, C., Martin, R., Wright, G., Flavel, R., Phan, S., Tighe, M. J. F. C. R. (2017). **Productivity and profitability of upland crop rotations in Northwest Cambodia**. 203: 150-162.

Mund, J.-P. J. P. N. (2011). **The agricultural sector in Cambodia: Trends, processes and disparities**. 35: 10-14.

Murshid, W.R., 1998. Management of minor head injuries: admission criteria, radiological evaluation and treatment of complications. Acta neurochirurgica, 140(1).56-64.

NSDP. (2009). **National Development Strategy Plan 2009-2013**. NATIONAL DEVELOPMENT STRATEGY PLAN 2009-2013.

Ong, K. L., Kaur, G., Pensupa, N., Uisan, K., & Lin, C. S. K. J. B. t. (2018). **Trends in food waste valorization for the production of chemicals, materials and fuels: Case study South and Southeast Asia**. 248: 100-112.

Onwueme, I. J. C. B. production, & utilization. (2002). **Cassava in Asia and the Pacific**. 55-65.

PDA-BB, (2017). **Provincial agricultural statistics 2009-2016**. Battambang: Provincial Department of Agriculture, Forestry and Fisheries in Battambang (PDAFF-BB).

PDA-PL, (2017). **Provincial agricultural statistics 2009-2016**. Pailin: Provincial Department of Agriculture, Forestry and Fisheries in Pailin (PDAFF-Pailin).

PROMKHAMBUT, A., MANUTA, P., LAOKEN, A., SUNGTHONGWISES, K., & POLTHANEE, A. (2015). **Effect of Stake Storage Methods on Germination, Growth and Yield of Cassava (Manihot esculenta Crantz.)**. International Journal of Environmental and Rural Development: 6(2). 110-114.

Provincial Department of Meteorology (2017). **Monthly rainfall and temperature at Battambang and Pailin province**.

Putthacharoen, S., Howeler, R. H., Jantawat, S., & Vichukit, V. J. F. C. R. (1998). **Nutrient uptake and soil erosion losses in cassava and six other crops in a Psamment in eastern Thailand**. 57(1): 113-126.

Sinthuprama, S., & Tiraporn, C. J. C. b. a. m. r. (1987). **Cassava varietal improvement in Thailand**. 227-240.

Sopheap, U., Makara, O., Howeler, R. H., & Aye, T. M. (2008). **Enhancing cassava production and utilization through Nippon Foundation project in Cambodia**. Paper presented at the A New Future for Cassava in Asia: Its Use as Food and Fuel to Benefit the Poor. Proceeding of 8th Regional Cassava Workshop.

Sopheap, U., Patanothai, A., & Aye, T. M. (2011). Farmers' perceptions on cassava cultivation in Cambodia. **Khon Kaen Agri. Jour**. 39: 279-294.

Socheth, H. (2012). **Foreign Investment in Agriculture in Cambodia: A survey of recent trends**. Manitoba: International Institute for Sustainable Development.

Stoorvogel, J. J., Smaling, E. M., & Janssen, B. J. F. r. (1993). **Calculating soil nutrient balances in Africa at different scales**. 35(3): 227-235.

Thomas, T. P., Sankar, S., & Unni, K. J. F. r. o. t. p. K. I. (2012). **A field study to evaluate the efficacy of lemon grass in controlling runoff and soil erosion**. 0970-8103.

Tongglum, A., Suriyapan, P., & Howeler, R. H. (2001). **Cassava agronomy research and adoption of improved practices in Thailand**: Major achievements during the past 35 years.

Touch, V., Martin, R. J., Scott, J. F., Cowie, A., & Li Liu, D. J. J. o. e. m. (2016). **Climate change adaptation options in rainfed upland cropping systems in the wet tropics**: A case study of smallholder farms in North-West Cambodia. 182: 238-246.

Villamayor Jr, F. G., & Davines, R. (1987). **Optimum time of planting and harvesting cassava in areas with a distinct wet and dry season**. Progress Report. ViSCA, Baybay, Leyte.

Wargiono, J., Y. Widodo and W.H. Utomo. 2001. **Cassava agronomy research and adoption of improved practices in Indonesia-Major achievements during the past 20 years**. In: R.H. Howeler and S.L. Tan (Eds.). Cassava's Potential in Asia in the 21st Century: Present Situation and Future Research and Development Needs. Proc. 6th Regional Workshop, held in Ho Chi Minh city, Vietnam. Feb 21-25, 2000.

Wenjun, O. (2016). **Current Situation of Cassava Production, Constraints and Opportunities in Cambodia**. Agriculture, Forestry and Fisheries, 5, 64. doi:10.11648/j.aff.20160503.16.

White, P.F., Oberthur, T. and Pheav, S. (1997). **The Soils Used for Rice Production in Cambodia**. A Manual for their Identification and Management. International Rice Research Institute, Manila.

Zhang, W., Lin, X., Li, K., Juang, J., Tian, Y., Lee, J., & Fu, Q. (1998). **Cassava agronomy research in China**. In: Centro Internacional de Agricultura Tropical (CIAT).

APPENDICES

APPENDIX A

Results of time of plant all trials for 2 year

Table A.1 Results at the Samlout site in 2017-18 season.

PLOT	REP	TRT	no. plants/plot	Total gross tuber yield	total net tuber wet yield (t/ha)	Starch content (Silo)	height of Single plant (cm)		single plant total above ground		no. tubers/single plant		4 plants total wet above ground		tuber weight 4 plants in air (kg)		no. tubers/4 plants		plant dry weight single plant (gm)		tuber dry weight single plant (gm)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	1	39	131.3	21.88	23.50%	153	132	1.41	1.15	11	9	3.26	2.88	7.7	14.7	26	31	800	720	305	360
2	1	4	56	124.8	20.80	24.10%	170	53	1.18	0.49	13	9	2.15	2.27	7.6	6	15	20	935	780	400	380
3	1	2	59	225.05	37.51	23.60%	140	160	0.69	0.59	8	14	2.56	4.06	12.2	16.1	37	53	270	2070	760	1,090
4	1	5	52	167.63	27.94	23.10%	142	107	0.84	0.5	13	6	6.53	2.42	23.8	11.4	56	30	320	290	970	350
5	1	3	58	218.17	36.36	22.50%	167	132	1.18	0.73	10	7	1.67	3.85	16.3	16.5	47	32	490	510	1,420	1,340
6	1	6	58	224.27	37.38	22.50%	150	138	1.05	0.8	8	11	3.03	2.23	11.5	11.5	28	24	540	360	890	990
7	2	1	58	126.01	21.00	23.90%	140	132	0.49	0.65	3	3	2.33	2.38	3.6	6.6	14	28	620	810	270	416
8	2	4	44	95.6	15.93	24.80%	161	95	1.21	0.43	6	4	4.07	1.64	4.4	8.4	10	23	200	197	99	102
9	2	2	61	214.96	35.83	24.90%	154	153	0.77	0.85	13	12	3.87	4.08	17.4	18	49	49	250	720	600	930
10	2	5	55	151.11	25.19	23.70%	138	71	0.93	0.13	9	2	2.5	1.6	12.6	6.4	38	22	430	30	610	50
11	2	3	56	186.01	31.00	21.70%	135	119	0.83	0.84	10	9	3.14	2.81	13.8	15.5	49	35	680	490	1,340	730
12	2	6	57	181.78	30.30	21.40%	138	117	1.18	0.76	8	11	3.78	3.23	15.5	12.5	36	37	560	390	1,000	1,490
13	3	1	48	130.86	21.81	24.60%	128	154	0.75	0.93	4	5	2.14	2.57	11	10	23	28	405	208	87	57
14	3	4	57	73.8	12.30	23.70%	107	136	0.48	0.57	1	2	2.89	1.51	4.3	3.3	6	9	860	1017	390	870
15	3	2	60	252.35	42.06	22.80%	158	150	0.58	1.1	12	11	3.68	3.14	15.4	16.6	48	47	260	430	590	1,000
16	3	5	49	118.72	19.79	24.40%	98	89	0.39	0.28	8	7	3.11	1.28	15.8	6.2	31	19	200	180	190	240
17	3	3	55	209.51	34.92	23.50%	170	122	1.59	0.82	11	7	5.05	3.02	18.5	13	42	31	830	500	982	740
18	3	6	54	227.41	37.90	24.90%	134	144	1.34	1.12	11	11	4.84	4.69	18.3	18	44	42	610	590	716	670
19	4	1	52	175.76	29.29	24.20%	134	108	0.17	0.28	7	5	4.11	2.66	15.9	12.4	49	34	780	900	290	285
20	4	4	34	90.39	15.07	23.80%	138	192	0.99	0.66	8	3	2.72	1.73	7.2	4.8	19	11	1025	907	680	720
21	4	2	59	232.32	38.72	23.20%	110	164	0.36	1.18	9	10	3.46	3.91	16.7	17	43	41	180	420	270	1,260
22	4	5	56	155.11	25.85	22.70%	148	182	0.83	2.08	8	9	3.19	1.73	15.2	5.4	32	19	1820	800	970	1,440
23	4	3	58	253.13	42.19	20.90%	164	144	1.54	1.08	14	10	4.8	5.76	17	21.8	24	34	920	690	1,410	1,500
24	4	6	55	203.17	33.86	24.20%	153	105	1.1	0.77	12	7	3.33	4.57	12.5	16	33	44	1210	1300	1,870	720

Table A.2 Results at the Samlout site in 2018-19.

PLOT	REP	TRT	no. plants/plot	Total gross tuber yield (kg/plot)	total net tuber wet yield (t/ha)	Starch content (Silo)	height of Single plant (cm)		single plant total above ground Biomass (kg)		no. tubers/single plant		4 plants total wet above ground Biomass (kg)		tuber weight 4 plants in air (kg)		no. tubers/4 plants		plant dry weight single plant (Kg)		tuber dry weight single plant (Kg)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	1	59	92.24	15.37	16.5%	113	117	0.37	0.78	6	8	2.18	2.68	3.9	5.3	19	24	0.17	0.14	0.23	0.28
2	1	4	68	66.58	11.10	15.5%	112	97	0.6	0.43	7	5	3.3	2.01	8.9	5.3	30	29	0.44	0.11	0.21	0.19
3	1	2	59	174.07	29.01	19.0%	85	156	0.31	1.59	9	13	3	4.36	11.8	16.6	48	49	0.05	0.67	0.33	1.93
4	1	5	57	177.79	29.63	19.7%	109	87	0.78	0.34	17	10	3.39	2.61	15.6	13	47	50	0.33	0.20	0.91	0.30
5	1	3	19	125.78	20.96	22.2%	175	145	3.25	1.26	14	8	4.72	8.89	12.8	13	23	26	0.51	0.58	2.08	1.13
6	1	6	12	55.02	9.17	20.6%	125	130	1.2	1.33	13	9	6.84	7.13	21.6	16	38	36	0.52	0.45	0.94	0.82
7	2	1	68	137.31	22.89	21.0%	142	173	0.43	1.09	5	13	4.02	3.08	11	10.7	37	35	0.16	0.40	0.25	0.92
8	2	4	62	49.25	8.21	18.0%	138	135	0.59	0.76	4	6	3.09	3.89	3.7	9.9	13	30	0.24	0.20	0.24	0.27
9	2	2	60	195.59	32.60	18.0%	93	135	0.41	0.89	7	7	3.15	3.99	13.4	16.6	43	53	0.18	0.53	0.34	0.97
10	2	5	55	112.19	18.70	21.0%	106	93	0.45	0.36	1	4	1.94	2.52	6.7	9.8	31	39	0.32	0.20	0.09	0.20
11	2	3	39	165.2	27.53	17.0%	143	146	0.65	0.97	8	10	8.05	6.3	17.6	19.5	25	35	0.38	0.47	0.24	0.55
12	2	6	29	72.69	12.12	19.9%	167	141	1.08	1.54	8	12	9.34	11.34	11.2	10.2	29	27	0.64	0.48	0.82	0.83
13	3	1	69	165.23	27.54	18.0%	148	139	0.86	0.73	14	12	2.47	3.2	9.09	14.8	10	51	0.20	0.25	0.64	1.16
14	3	4	68	111.56	18.59	21.0%	149	90	0.73	0.3	7	6	2.38	2.33	5.7	2.6	31	12	0.14	0.33	0.33	0.92
15	3	2	58	187.19	31.20	21.0%	96	135	0.69	0.89	13	11	3.4	4.24	13.3	14.6	47	37	0.36	1.04	0.56	2.22
16	3	5	55	174.38	29.06	17.9%	85	129	0.33	0.98	12	11	2.19	2.73	11.2	11	39	47	0.21	0.96	0.36	1.03
17	3	3	59	192.77	32.13	18.9%	153	134	1.57	0.32	15	5	6.5	5.15	20.7	14.8	38	25	0.68	0.77	1.52	0.46
18	3	6	49	185.73	30.96	17.2%	195	170	2.26	2.42	7	10	5.82	6.95	14.5	29.1	32	29	1.24	1.06	0.94	0.82
19	4	1	69	136.9	22.82	15.5%	113	117	0.46	0.48	7	7	2.28	2.23	10	8.8	32	41	0.18	0.19	0.51	0.34
20	4	4	66	47.93	7.99	23.0%	125	123	0.82	0.72	9	5	3.32	2.06	6	3.2	26	22	0.29	0.22	0.72	0.48
21	4	2	54	194.92	32.49	19.7%	149	200	1.27	1.18	9	17	3.62	4.61	16.2	19.8	49	50	0.46	0.86	0.97	1.58
22	4	5	55	192.12	32.02	21.0%	108	115	0.1	0.91	8	16	2.8	3.12	13.7	14.6	43	46	0.31	0.60	0.42	0.82
23	4	3	52	215.73	35.96	20.9%	140	159	0.87	0.83	8	8	6.7	5.96	20	19.2	41	36	0.40	0.48	1.28	0.89
24	4	6	54	151.12	25.19	22.1%	130	174	0.29	2.94	5	11	6.43	5.58	15.8	12.1	37	22	1.27	0.27	1.83	0.50

Table A.3 Results at the Pailin site in 2017-18.

PLOT	REP	TRT	no. plants/plot	Total gross tuber yield (kg/plot)	total gross tuber wet yield (t/ha)	Starch Content (Silo)	height of Single plant (cm)		single plant total above ground		no. tubers/single plant		4 plants total wet above ground		tuber weight 4 plants in air (kg)		no. tubers/4 plants		plant dry weight single plant (gm)		tuber dry weight single plant (gm)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	1	53	199.35	33.23	24.80%	100	167	0.27	0.84	3	10	1.56	3.46	10.6	16.5	22	28	639	892	937	1,192
2	1	4	56	196.76	32.79	24.60%	167	120	0.88	0.48	5	7	2.88	3.23	13.3	16.35	34	47	536	970	214	720
3	1	2	59	228.64	38.11	19.80%	160	145	0.84	0.5	9	4	2.69	4.13	12	29.2	25	33	400	763	1,380	403
4	1	5	60	237.84	39.64	23.00%	171	203	0.96	1.17	6	11	3.87	4.52	11.4	12.8	32	37	310	510	1,950	450
5	1	3	54	170.36	28.39	22.60%	141	93	0.61	0.44	7	4	3.24	0.88	11.8	1.6	29	10	310	480	820	540
6	1	6	57	91.02	18.20	23.90%	76	67	0.22	0.29	5	6	2.48	3.21	5.4	9	16	25	600	750	1,160	980
7	2	1	57	209.82	34.97	25.10%	84	194	0.25	1.26	3	10	3.09	4.03	7	21.5	31	40	834	580	396	230
8	2	4	59	185.62	30.94	23.20%	164	180	0.69	0.9	2	13	2.37	2.24	4.2	18.7	12	36	503	200	157	115
9	2	2	52	152.00	25.33	19.40%	106	152	0.59	0.82	8	7	4.08	2.04	16.6	8.2	32	19	2890	420	1,040	1,400
10	2	5	52	228.06	38.01	19.80%	143	210	0.39	1.64	3	16	4.99	4.7	19.8	19.5	44	47	2330	1920	800	1,850
11	2	3	60	172.49	28.75	23.20%	133	115	0.45	0.66	9	9	2.17	3.49	6.8	13.2	17	32	440	390	1,490	880
12	2	6	58	144.12	28.82	24.40%	170	109	1.18	0.67	8	6	3.83	1.77	13.2	6	23	18	830	330	440	340
13	3	1	60	183.39	30.57	24.60%	193	218	1.02	1.73	10	17	2.21	4.97	19.4	20.6	38	46	250	420	80	225
14	3	4	58	108.60	18.10	23.90%	177	150	1.52	0.42	4	3	1.5	2.01	5.65	6.45	14	16	620	620	380	1,590
15	3	2	53	146.78	24.46	23.00%	160	205	0.85	1.29	11	10	4.88	3.03	21	14.1	36	28	360	440	1,550	164
16	3	5	57	230.38	38.40	23.00%	203	185	0.75	0.91	9	13	5.21	4.52	19.2	26.5	50	55	390	400	1,300	116
17	3	3	59	125.98	21.00	22.70%	136	124	0.48	1.07	6	7	3.59	3.19	10.3	11	30	24	150	610	600	1,010
18	3	6	58	153.91	30.78	24.10%	150	160	1.08	0.8	19	12	3.99	3.04	14.5	12.6	28	25	240	460	390	280
19	4	1	57	251.42	41.90	24.40%	178	143	0.74	0.65	12	7	2.73	4.7	13.5	20.9	36	50	734	784	386	326
20	4	4	58	139.38	23.23	24.80%	137.2	131	0.63	0.5	4	5	3.06	2.81	4.85	8.4	10	20	990	430	903	367
21	4	2	57	106.47	17.75	24.00%	160	187	0.9	1.06	5	7	4.19	3.1	4.5	8.2	14	20	240	600	190	750
22	4	5	58	189.72	31.62	23.80%	233	180	2.21	0.67	3	5	4.41	4.93	16.1	8.65	32	30	1020	980	650	670
23	4	3	59	134.22	22.37	21.40%	86	128	0.33	0.73	7	10	2.49	2.57	9.50	9.30	30.00	29.00	200	310	440	340
24	4	6	57	140.83	28.17	23.50%	168	82	0.77	0.39	9	11	3.46	1.84	13.50	6.50	30.00	15.00	189	178	420	189

Table A.4 Results at the Pailin site in 2018-19.

PLOT	REP	TRT	no. plants/ plot	Total gross tuber yield (kg/plo	total gross tuber wet yield	Starch Content (%)	height of Single plant (cm)		single plant total above ground		no. tubers/single plant		4 plants total wet above ground		tuber weight 4 plants in air (kg)		no. tubers/4 plants		plant dry weight single plant (kg)		tuber dry weight single plant (kg)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	1	59	128.3	26.74	24.00%	151	145	0.4	0.83	7	8	2.32	2.01	13.4	11.4	43	28	0.26	0.24	1.18	1.39
2	1	4	54	165.7	34.52	19.50%	148	153	0.7	1.23	12	12	3.01	3.06	17.8	15.7	26	25	0.39	0.50	1.36	2.04
3	1	2	45	67.53	14.07	21.20%	137	116	0.62	0.51	7	7	2.43	2.27	9.5	9	28	26	0.41	0.41	0.88	0.81
4	1	5	37	71.42	14.88	21.50%	125	112	0.62	0.4	9	7	2.6	2.42	12.4	11	32	31	0.32	0.29	0.91	0.64
5	1	3	29	51.49	10.73	22.80%	115	110	0.48	0.65	2	4	3.1	5.2	10	9.2	16	21	0.38	0.39	0.36	0.08
6	1	6	20	57.16	11.91	22.70%	163	120	1.13	0.89	4	2	6.75	3.34	12.8	6.1	13	13	0.51	0.28	0.36	0.38
7	2	1	55	151.7	31.6	21.00%	133	128	0.69	0.44	7	10	3.6	4.68	16.3	19.2	27	28	0.29	0.70	1.17	0.88
8	2	4	54	137	28.54	22.50%	118	195	0.28	1.25	5	8	3.82	3.17	13.4	17.4	32	40	0.16	0.61	0.49	1.60
9	2	2	45	131.7	27.43	21.80%	140	130	0.66	0.68	8	10	2.55	2.09	14.2	8.4	31	21	0.44	0.52	1.12	1.29
10	2	5	39	141.4	29.45	20.60%	120	96	0.2	0.13	5	4	3.21	3.67	14.8	15.4	37	40	0.34	0.15	0.67	0.19
11	2	3	10	13.78	2.871	20.60%	100	102	0.49	0.46	5	2	4.52	2.33	8	4.2	29	19	0.21	0.25	0.24	0.16
12	2	6	13	54.1	11.27	21.80%	150	138	1.09	0.91	6	6	2.93	4.26	5.5	8.9	19	21	0.56	0.40	0.76	0.57
13	3	1	54	133.4	27.79	26.30%	126	145	0.42	0.76	8	5	2.93	4.09	10.55	17.4	35	26	0.23	0.30	0.62	1.13
14	3	4	55	80.98	16.87	20.50%	145	157	0.7	0.97	9	7	3.26	3.54	8	7.2	33	24	0.32	0.47	0.90	1.23
15	3	2	41	85.92	17.9	21.20%	126	124	0.71	1.05	10	9	2.67	2.2	12.2	9.6	28	26	0.53	1.38	1.38	2.92
16	3	5	43	159	33.13	20.80%	140	116	0.59	0.18	4	6	4.43	4.63	13.3	17.6	23	43	0.43	0.30	0.81	0.52
17	3	3	10	31.49	6.56	19.60%	137	93	0.62	0.48	7	1	4.14	5.35	10	18	29	33	0.41	0.24	0.64	0.19
18	3	6	17	24.88	5.183	19.90%	114	109	0.34	0.66	6	4	2.24	5.24	3.8	3.8	14	16	0.31	0.37	0.21	0.26
19	4	1	52	88.94	18.53	23.50%	155	160	0.76	1.06	7	8	2.69	4.4	7.2	8.9	18	18	0.38	0.74	0.88	0.52
20	4	4	59	83.45	17.39	24.30%	129	112	0.61	0.73	3	6	4.7	3.17	7	7.1	22	30	0.28	0.24	0.32	0.49
21	4	2	39	99.48	20.73	21.30%	125	142	0.3	0.26	4	10	1.76	2.36	8.5	11.5	27	25	0.20	0.50	0.31	0.79
22	4	5	39	147.2	30.66	22.10%	129	149	0.28	1.22	5	7	4.29	4.81	15	18.5	24	30	0.25	0.84	0.69	0.86
23	4	3	11	22.7	4.729	20.60%	135	172	1.06	1.59	5	6	2.98	3.23	6.20	9.10	21	22	0.56	0.82	0.67	0.52
24	4	6	13	31.81	6.627	21.70%	84	113	0.35	0.73	3	8	2.52	6.68	5.80	13.90	22	31	0.16	0.28	0.10	0.46

APPENDIX B

Results of cassava planting method all trials for 2 year

Table B.1 Results at the Samlout site in 2017-18.

PLOT	REP	TRT	no. plants/plot	Total gross tuber yield (kg/plot)	total net tuber wet yield (t/ha)	Starch content (Silo)	height of Single plant (cm)		single plant total above ground Biomass (kg)		no. tubers/single plant		4 plants total wet above ground Biomass (kg)		tuber weight 4 plants in air (kg)		no. tubers/4 plants		plant dry weight single plant (gm)		tuber dry weight single plant (gm)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	2	62	169.82	28.30	23.40%	183	112	1.41	0.43	9	4	2.58	4.13	9.2	8	30	26	600	1,050	760	905
2	1	1	59	108.53	18.09	24.20%	123	139	0.73	0.94	5	5	3.66	4.47	3	6.44	15	15	250	1,630	420	1,150
3	1	3	35	30.93	5.16	23.70%	125	104	1.16	0.62	6	3	4.85	2.76	1.43	3.4	8	16	1,350	1,280	1,320	1,000
4	1	4	54	37.78	6.30	23.40%	100	190	0.48	2.13	5	6	3.87	2.94	3.4	4	9	20	1,200	1,300	930	1,140
5	1	6	55	33.2	5.53	23.80%	122	167	0.57	1.47	5	4	2.45	2.7	1.11	3.85	7	5	890	870	908	915
6	1	5	55	36.43	6.07	23.80%	169	48	2.2	0.19	13	3	4.21	1.44	4.1	2.6	18	14	520	100	480	120
7	2	1	54	91.28	15.21	24.10%	105	100	0.81	0.54	9	5	1.79	1.91	5.4	4.8	20	18	200	220	980	190
8	2	2	61	120.04	20.01	23.70%	116	144	0.4	0.94	6	10	3.7	3.45	10	7	30	23	270	310	200	1,670
9	2	4	61	67.81	11.30	23.60%	130	115	0.41	0.59	6	4	4.55	4.73	5.9	4.4	23	18	390	600	1,340	860
10	2	3	62	48.01	8.00	23.20%	130	105	0.88	0.38	10	3	3.33	1.95	5.2	1.9	21	10	700	852	940	750
11	2	6	60	29.88	4.98	23.70%	154	114	1.36	0.35	10	4	2.5	2.69	0.73	2.51	7	14	520	150	610	290
12	2	5	57	25.58	4.26	22.90%	103	69	0.34	0.36	1	6	2.12	1.43	0.88	3.4	6	21	430	180	130	840
13	3	1	62	104.63	17.44	23.10%	100	60	0.68	0.08	8	3	2.96	1.54	9.4	3.4	25	20	340	770	440	930
14	3	2	57	126.59	21.10	23.80%	169	204	0.88	2.07	5	9	6.87	10.8	6.2	20	23	35	300	110	1,460	880
15	3	4	46	29.75	4.96	24.20%	96	106	0.25	0.3	3	1	2.28	3.62	0.84	2.15	8	17	40	240	1,590	70
16	3	3	58	38	6.33	23.40%	160	117	2.88	1.02	10	8	4.22	2.29	3.8	1.46	17	9	460	170	370	630
17	3	5	53	26.51	4.42	23.60%	99	123	0.37	0.41	8	4	3.89	1.9	3.2	0.58	16	5	300	180	520	178
18	3	6	59	54.79	9.13	23.60%	150	116	0.79	0.64	7	6	2.85	2.36	4.65	1.7	22	7	270	233	540	97
19	4	1	58	121.9	20.32	22.60%	80	95	0.39	0.36	5	3	3.63	2.93	18.25	6.9	24	26	920	110	960	320
20	4	2	48	105.92	17.65	24.10%	114	165	0.72	1.62	5	10	5.52	1.87	12.5	1.5	24	18	290	200	450	170
21	4	3	20	1.9	0.32	23.60%	147	127	0.58	0.52	8	2	1.93	1.29	0.68	0.31	8	5	480	340	180	385
22	4	4	58	56.8	9.47	23.80%	137	97	1.22	0.33	6	4	6.67	3.92	5	4	14	5	340	170	300	840
23	4	6	60	58.72	9.79	23.90%	142	126	1.17	0.62	4	3	2.75	2.15	5	1.41	18	7	430	430	550	860
24	4	5	55	83.55	13.93	23.40%	143	89	1.42	0.63	4	5	3	2.02	6.2	2.14	25	12	450	740	540	1,310

Table B.2 Results at the Samlout site in 2018-19.

PLOT	REP	TRT	no. plants/plot	Total gross tuber	total net tuber wet yield	Starch content (Silo)	height of Single plant (cm)		single plant total above ground Biomass (kg)		no. tubers/single plant		4 plants total wet above ground Biomass (kg)		tuber weight 4 plants in air (kg)		no. tubers/4 plants		plant dry weight single plant (kg)		tuber dry weight single plant (kg)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	2	37	105.4	17.57	19.80%	168	161	1.75	1.48	12	6	1.55	3.59	14.8	20.1	24	41	1.03	0.89	3.73	0.42
2	1	1	27	74.24	12.37	20.10%	125	97	0.94	0.69	11	11	2.13	3.04	10	9	29	18	0.55	0.45	1.50	0.70
3	1	3	31	75.44	12.57	21.50%	95	97	0.47	0.54	17	10	1.68	2.25	5.6	6	19	21	0.50	0.48	1.11	1.50
4	1	4	19	38.83	6.47	21.00%	127	103	0.44	0.28	6	8	3.25	2.78	11.4	7.1	30	21	0.29	0.18	0.67	0.37
5	1	6	12	22.06	3.68	19.50%	143	90	1.15	0.28	14	3	1.45	1.75	6	6.1	13	15	0.59	0.10	1.03	0.19
6	1	5	18	24.18	4.03	19.20%	94	116	0.32	0.68	3	6	0.37	2.33	4.1	9.5	20	25	0.17	0.34	0.50	0.68
7	2	1	38	78.88	13.15	21.80%	85	117	0.46	1.06	6	8	1.46	1.79	6.2	9.9	17	24	0.23	0.57	0.36	0.95
8	2	2	44	173.88	28.98	22.00%	160	136	0.29	1.01	7	18	3.15	4.98	16.8	24.4	36	48	0.41	0.53	0.50	1.08
9	2	4	22	84.49	14.08	19.50%	143	115	0.89	0.36	15	8	2.57	3.02	10.1	12.8	28	43	0.93	0.50	1.99	0.72
10	2	3	31	91.46	15.24	19.60%	100	115	0.51	0.53	6	10	2.72	4.56	12.1	11.2	40	43	0.30	0.47	0.43	0.86
11	2	6	19	39.36	6.56	20.10%	91	96	0.66	0.27	6	10	3.48	1.85	7.8	2.8	18	13	0.32	0.38	0.50	0.53
12	2	5	11	19.99	3.33	19.00%	93	114	0.75	0.42	7	9	1.62	1.36	3.7	6.3	14	21	0.36	0.33	0.71	1.22
13	3	1	37	86.57	14.43	18.80%	114	96	0.63	0.78	8	7	5.9	4.94	9.4	11.6	20	17	0.45	0.51	0.55	1.10
14	3	2	30	110.03	18.34	19.00%	164	167	1.41	1.79	7	15	9.62	4.64	6	12.98	16	16	0.51	1.19	1.24	3.38
15	3	4	28	101.2	16.87	18.30%	114	137	0.91	0.87	12	10	1.24	6.3	6	18	19	38	1.00	0.51	2.14	0.73
16	3	3	45	115.21	19.20	17.20%	148	170	1.27	3.04	10	12	3.99	2.57	13	20	44	44	0.80	1.57	1.22	2.26
17	3	5	23	52.29	8.72	17.80%	60	30	0.27	0.07	6	2	4.23	1.59	17.4	4.8	28	11	0.13	0.08	0.27	0.14
18	3	6	23	34.85	5.81	18.50%	102	62	0.91	0.15	5	5	4.57	0.8	11.8	2.2	28	11	0.51	0.13	0.30	0.18
19	4	1	34	111.97	18.66	21.00%	46	121	0.05	0.99	4	9	9.7	2.12	23	9.6	38	16	0.07	0.70	0.13	1.27
20	4	2	36	131.16	21.86	20.80%	169	130	1.05	0.97	12	20	2.56	1.84	12.8	6.8	31	18	0.39	0.40	1.59	1.08
21	4	3	21	70.05	11.68	21.20%	85	149	0.18	2.94	8	15	5.11	7.07	9	17	20	16.9	0.15	0.81	1.05	1.42
22	4	4	30	74.22	12.37	20.70%	67	149	0.1	0.76	7	15	3.47	3.38	10	11.1	26	35	0.22	0.56	0.19	1.12
23	4	6	31	76.05	12.68	21.50%	137	148	0.87	1.14	7	12	2.76	4.46	10	16.5	31	31	0.50	0.96	0.18	1.91
24	4	5	21	31.69	5.28	18.50%	137	110	0.99	0.37	12	8	1.63	3.92	4.8	6.3	19	18	0.61	0.30	1.27	0.69

Table B.3 Results at the Pailin site in 2017-18.

PLOT	REP	TRT	no. plants/ plot	Total gross tuber yield (kg/plot)	total gross tuber wet yield (t/ha)	Starch Content (Silo)	Height of Single plant (cm)		single plant above ground biomass (kg)		no. tubers/single plant		4 plants total above ground Biomass (kg)		tuber wet weight 4 plants (gm)		no. tubers/4 plants		plant dry weight single plant (gm)		tuber dry weight single plant (gm)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	1	52	233.64	38.94	22.90	89	130	0.17	0.49	4	4	4.06	6.19	18	16.4	46	28	166	190	74	490
2	1	2	59	215.16	35.86	18.40	165	126	1.05	0.86	5	6	4.12	4.25	16.7	16.2	39	33	204	400	676	137
3	1	4	53	242.7	40.45	18.40	190	204	1.31	1.5	11	10	4.16	5.56	13.3	23.2	26	45	660	1193	2140	917
4	1	3	45	109.09	18.18	21.70	120	104	0.43	0.53	13	10	3.57	3.28	15.2	14.2	34	32	520	930	330	320
5	1	5	57	163.05	27.18	19.60	134	142	0.58	0.68	9	10	2.74	3.16	12.4	11	26	22	330	977	690	513
6	1	6	59	223.49	37.25	19.20	190	206	1.5	1.76	11	10	3.41	6.03	11.25	13.6	30	30	833	1226	347	644
7	2	2	56	116.54	19.42	23.20	105	144	0.29	0.68	6	4	2.03	3.6	1.16	7.8	7	26	1990	485	2100	255
8	2	1	57	146.3	24.38	19.00	150	150	0.77	1.25	3	7	4.25	2.88	12.5	5.2	28	13	285	976	135	464
9	2	3	59	154.32	25.72	19.80	226	176	1.52	0.97	5	8	4.91	4.85	12.5	14.4	21	30	1236	900	514	930
10	2	4	52	95.69	15.95	20.10	134	107	0.68	0.72	6	4	3.05	3.06	6	7.6	19	26	320	420	380	220
11	2	6	57	104.58	17.43	22.60	164	100	0.69	0.39	10	6	2.51	3.01	10.8	3.27	37	19	772	277	428	113
12	2	5	56	140.81	23.47	19.80	150	237	0.95	2.61	7	13	2.92	3.82	5.95	15	15	29	270	1510	300	1350
13	3	1	60	139.16	23.19	20.60	153	138	0.47	0.68	6	3	2.84	2.99	2.4	12	11	24	219	624	187	316
14	3	2	57	131.48	21.91	22.90	132	160	0.59	1.1	6	7	2.95	3.85	8.8	6.4	31	18	63	1130	36	405
15	3	3	46	80.39	13.40	19.50	133	128	0.56	0.4	9	4	1.32	1.31	6.6	3.4	29	12	734	836	386	245
16	3	4	49	71.73	11.96	22.80	90	130	0.17	0.67	4	8	1.13	1.62	1.91	4	11	15	130	350	180	140
17	3	5	24	49.55	8.26	26.30	83	105	0.29	1.07	2	3	2.69	2.38	6.3	7.32	22	27	1031	80	859	239
18	3	6	57	118.34	19.72	23.90	125	146	0.59	0.91	4	6	2.72	3.27	3.12	10.7	14	23	1443	859	497	451
19	4	1	45	115.33	19.22	20.80	125	133	0.72	0.55	5	6	3.67	5.16	8.9	15.1	25	35	630	605	1140	335
20	4	2	58	151.4	25.23	23.80	162	135	1.07	0.42	9	5	5.1	4.16	18	4.8	50	18	650	650	1460	270
21	4	3	53	105.21	17.54	24.20	139	144	0.96	0.9	5	9	3.39	2.3	8.8	9.8	23	23	961	1034	369	646
22	4	4	57	106.19	17.70	24.90	153	138	1.02	0.71	5	4	4.23	3.26	9.6	5.2	27	14	224	213	446	157
23	4	5	26	23.73	3.96	25.70	85	140	0.27	0.53	5	3	3.68	3.12	4.6	3.9	15	20	264	218	146	272
24	4	6	52	52.37	8.73	24.90	184	124	1.04	0.49	3	2	3.04	2.56	2.46	4.2	10	19	180	493	600	197

Table B.4 Results at the Pailin site in 2018-19

PLOT	REP	TRT	no. plants/plot	Total gross tuber yield (kg/plot	total gross tuber wet yield	Starch Content (%)	Height of Single plant (cm)		single plant above ground biomass (kg)		no. tubers/single plant		4 plants total above ground Biomass (kg)		tuber wet weight 4 plants (gm)		no. tubers/4 plants		plant dry weight single plant (kg)		tuber dry weight single plant (kg)	
							Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B	Sub sample A	Sub sample B
1	1	1	21	63.59	13.25	20.5	135	120	1.16	0.84	5	5	1.96	4	8	13	24	25	1.33	0.98	1.64	1.34
2	1	2	15	59.56	12.41	21.7	130	142	0.8	0.94	4	4	5.39	5.35	17.7	17.4	27	34	1.38	2.04	2.64	2.41
3	1	4	14	50.76	10.58	22	120	136	0.66	1.02	5	8	4.03	2.52	14.4	8.4	27	17	0.46	0.88	1.15	1.20
4	1	3	20	42.76	8.91	18.7	127	120	0.97	0.49	3	6	3.43	1.22	9.4	7.5	25	24	1.13	0.51	0.67	0.37
5	1	5	22	31.66	6.60	16.7	80	135	0.2	0.41	6	4	2.48	2.25	8.8	6.2	25	14	0.46	0.47	0.70	1.14
6	1	6	23	50.16	10.45	22	136	90	1.34	0.31	4	2	2.28	2.28	7.8	9.5	22	18	0.17	0.34	0.50	0.68
7	2	2	21	58.2	12.13	21.8	105	108	0.52	0.94	2	7	2.6	1.85	7.5	5.4	17	15	0.70	1.14	0.62	1.74
8	2	1	15	57.87	12.06	20.8	100	146	0.44	0.98	5	5	3.54	2.9	14.9	17.8	21	29	1.02	0.78	1.26	2.08
9	2	4	14	57.39	11.96	19.5	118	51	1.06	0.23	7	4	3.83	5.69	11.8	20	33	35	1.80	0.42	1.26	0.20
10	2	3	16	53.89	11.23	19.4	136	103	1.31	0.42	7	5	4.09	3.49	15.6	13.7	40	26	0.51	0.39	1.11	0.99
11	2	6	26	52.87	11.01	20.3	143	130	0.96	0.87	7	3	5.16	1.63	18	6	26	19	2.00	1.12	2.10	1.72
12	2	5	11	46.89	9.77	21.5	100	104	0.82	0.54	7	8	3.43	1.6	10.5	14.5	27	39	1.32	0.38	2.16	1.96
13	3	1	17	68.46	14.26	16.7	93	98	0.42	0.34	4	5	1.61	3.27	6.8	13.9	16	31	0.44	0.26	0.92	1.76
14	3	2	24	41.95	8.74	16.4	100	115	0.52	0.65	5	6	1.4	3.18	4.5	10.9	16	29	0.72	0.52	1.30	1.96
15	3	3	22	45.55	9.49	16.8	103	124	0.32	0.61	4	8	3.01	3.82	11.4	14.4	31	26	0.94	0.92	0.95	1.44
16	3	4	22	62.25	12.97	21.8	120	94	1.4	0.56	10	9	3.98	2.33	16.5	8.2	36	18	2.98	0.28	3.06	1.20
17	3	5	17	30.35	6.32	19.2	130	100	1.17	0.29	4	4	4.14	2.23	13.4	7	29	20	0.44	0.22	0.39	1.48
18	3	6	14	24.49	5.10	20.9	100	104	0.57	0.8	6	5	1.13	2.31	5	7.9	16	12	0.21	0.86	1.14	0.50
19	4	1	21	48.47	10.10	15.3	88	116	0.52	0.84	7	5	2.61	2.43	6.8	7.4	25	24	1.80	0.98	0.33	1.26
20	4	2	20	36.88	7.68	18.5	120	120	0.9	0.72	5	6	1.1	1.5	6.5	6.2	21	26	1.34	0.68	1.10	0.86
21	4	3	29	43.33	9.03	14.5	119	137	0.68	0.9	8	10	1.54	1.63	3.4	4.6	17	20	0.78	1.58	1.28	1.60
22	4	4	19	34.91	7.27	20.4	80	114	0.43	0.65	6	8	1.5	1.87	5	5.2	21	18	1.00	0.48	0.26	1.06
23	4	5	18	17.83	3.71	20.8	80	80	0.29	0.34	6	4	2.11	1.21	6.8	2.4	23	11	0.62	1.44	0.66	2.38
24	4	6	18	29.9	6.23	22.1	109	147	0.63	1.13	3	5	1.66	2.24	3.3	7	13	14	0.92	1.36	1.00	1.52

APPENDIX C

Field activities all trial sites

Figure C.1 Field activities at Samlot and Pailin trial site in 2017-18.

Figure C.2 Soil moisture measurement and harvest cassava at Samlot and Pailin trial site in 2017-18

BIOGRAPHY

Mr. Sophanara Phan was born on 02 January, 1980 at Ksam village, Ksam commune, Kompong Chhnang city, Kompong province, Cambodia. He graduated with the Bachelor Degree of Agriculture Science in 2005, Prek Leap National School of Agriculture, Phnom Penh, Cambodia. Then, in 2019, he was received jointly funded for master degree by this ACIAR project along with the scholarship programme at Suranaree University of Technology (SUT), Nakorn Ratchisema, Thailand. His research topic was farming systems options to enhance the production and sustainability of cassava in Northwest Cambodia.