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Development of a Decision Support Framework to Assist with Fertilizer Decisions in Myanmar

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ABSTRACT

Myanmar is an agricultural country with substantial development potential, having abundance of land, water and labor resources. Despite this, agricultural productivity in Myanmar is low and smallholder farm profits and incomes are amongst the lowest in Asia. Many reports have documented that the underperformance of crops and low yield is mainly due to the low use of fertilizers by smallholders in Myanmar.

Fertilizer application is an important strategy in increasing crop yield. However, determining the "Right Rate" at the "Right Time" is challenging to achieve economic, social and environmental goals. Many decision support tools (DSTs) have been developed to support farmers in making better informed fertilizer management decisions. Such tools allow farmers to use fertilizers more efficiently and increase production, reduce risks, save resources and gain more profit with a lower detrimental impact on the environment. DSTs are developed to be a solution and support farmers in Myanmar with their fertilizer decisions. However, there is limited evidence of the acceptability and successful ongoing uptake of DSTs by farmers throughout the world.

A review of the literature suggested that agricultural DSTs, in general, have suffered from low levels of use, apparently due to limited acceptability by end users. Reasons for this include lack of user participation in the initial design and development of the tools, complexity of earlier DST versions, insufficient training and technical support and limited on-going funding for DST maintenance. Participatory approaches to include farmers as users have been investigated to improve the design and development of DSTs. The complexity of the tools has been simplified into decision support smartphone apps but delivering useful information that represents and relates to farmer decision making remains important. A strong emphasis on the farmer decision-making processes with respect to economics and risks are still required for wider adoption of DSTs. New technologies that integrate socio-economic factors into farmer decision making are likely to be valuable. Thus, this study aims to develop a decision support framework to assist farmers with their fertilizer decisions in Myanmar.

Data were obtained from a survey of 600 smallholders in Tatkon, Zeyarthiri and Taungoo Townships in the central Dry Zone of Myanmar. The survey was conducted using CommCare®, a mobile application for data collection. Field experience in the design and implementation of using CommCare® to collect data for a complex farming system in Myanmar was discussed along with the recommendations which may allow other researchers to conduct a smooth and successful survey using similar mobile data collection process.

The survey results provided valuable information on fertilizer use to test whether the reportedly low levels of fertilizer use by Myanmar smallholders are generally true for central Myanmar and compared the timing of fertilizer application practices of smallholders against recommended "Good Management Practices". There have been concerns over the national data quality with very limited evidence in Myanmar. This is the first substantive study in Myanmar to compare smallholder fertilizer use with national recommended rates and report the fertilizer application times on cereal crops (rice and maize). Smallholders used both urea and compound fertilizers for cereal crops. For rice, the average amount of fertilizer applied was much higher than the reported national-level data of average fertilizer use. With respect to the timing of applications, smallholders were mostly aligned with recommended practices for Nitrogen (N), except that nearly half of the surveyed smallholders were not applying N at that the estimated panicle initiation stage, which is crucial to increase yield. With respect to applying Phosphorus (P), the majority (82%) of smallholders were applying as compound fertilizer throughout the growth stages when earlier application of P is recommended. Smallholder farmers may also be able to reduce the cost of labor by reducing the number of P applications and avoiding late applications. These results have enabled a better understanding of smallholder farmer utilization and management of fertilizers, their experiences and their livelihoods which remain crucial in designing and implementing sustainable interventions.

The survey also provided information on farmers' use of smartphones and agricultural mobile applications (apps) and analyzed factors affecting their use. This was used to assess the potential for farm-based decision support. In Myanmar very little literature relates to perceptions and use of Information and Communication Technologies (ICTs) and no study has considered factors related to the use and adoption of mobile apps in the Myanmar agricultural sector. Given the low uptake of decision support tools/apps by farmers throughout the world, this study provides valuable context for discussing farmer perceptions and what factors need to be considered in developing and scaling up mobile applications. A Probit analysis indicated that when introducing mobile-based tools, focus should be given to younger, more educated farmers growing more specialized crops. Smallholder farmers in Myanmar were found to be optimistic and positive towards agricultural apps, but there were many barriers including limited access to smartphones, lack of digital knowledge, and high cost of internet for effective utilization. However, most surveyed farmers were familiar with information received through Facebook groups. Incorporating useful information and functions from an agricultural mobile app to a Facebook Page could have a more useful and sustainable impact, at the same time eliminating the issues such as lack of awareness, lack of use and long-term servicing and sustainability. This new knowledge is important as many agricultural mobile apps have been developed and are continuing to be developed for decision support to farmers, when these apps have not been widely utilized by farmers.

Another reason for the limited use is that the tools do not account for complex and heterogeneous smallholder farming systems. Farm typology analysis has facilitated transfer and adoption of appropriate technologies to target groups of farmers with similar circumstances. It is important to consider the heterogeneity of farmer groups if DSTs are to be designed to reflect the needs of targeted end users. Typology analysis was further applied to the survey dataset to distinguish farmer groups with similar socio-economic characteristics. Six distinct groups of farms were identified. A qualitative participatory research approach with smallholders from each farm type was subsequently conducted to identify potential adopters of a DST for fertilizer management. Only one group of farmers indicated that DSTs could be useful in gaining more information and knowledge. These farmers were more likely to adopt a fertilizer DST than other farmer groups. Farmers who were interested in the technology indicated that Discussion Groups are a better learning environment and preferred a learning-based tool rather than a prescription-based tool. Discussion Support is a collaborative approach between farmers, whereas Decision Support is a more instructive approach providing recommendations which can be misinterpreted.

Discussion Support can be used by individual farmers, groups of farmers, or a group of farmers with extension officers enabling discussion of alternative management decisions, asking specific questions and seeking new ideas about adjusting farm decisions to meet smallholder management objectives. Farmers expressed preferences for video clips and infographics integrated into digital platforms, including social media and existing agri apps. Integrating a participatory research framework with typology identification is potentially valuable in assessing new technologies and may have a beneficial role in direct interactions with smallholders. This framework creates an opportunity to implement farmers' suggestions and opinions, which can be a valuable resource for further information system (IS) and decision support system (DSS) researchers.

The proposed decision support framework is to abandon the traditional DST approach, which is to be considered as a "black box", complex requiring substantial manual data entry requirements which are not attractive to farmers. Instead, this framework suggests on-going participatory approaches with farmers to gain their trust, integrate their inputs and implement their suggestions, identify specific groups of farmers as early adopters, utilize social media platforms to deliver discussion support outputs which are readily usable in the form of video clips and infographics and develop a discussion support format where farmers can discuss and learn from each other. Considerable care should be taken to ensure that farmers' socio-economic factors and decision-making contexts are also considered.

In the case of smallholders in central Myanmar, there was very little evidence from the field survey in support of the perception that Myanmar farmers are using low levels of fertilizers. The results indicated the farmers appeared to be substantially following good fertilizer management practices and decision support should be focused on other management practices instead of fertilizer.

Keywords:

Myanmar; decision support tools; fertilizer management; cereal crops; decision making; smallholder; mobile application; typology; participatory research

DECLARATION

This is to certify that:

(i) the thesis comprises only my original work toward the PhD and none of this work has been submitted for any other degree

(ii) due acknowledgement has been made in the text to all other material used

(iii) the thesis is fewer than 100,000 words in length, exclusive of tables, maps, bibliographies, and appendices

So Pyay Thar

Date: April 2021

PREFACE

This thesis is a "thesis with publication". It includes eight chapters, an Introduction chapter, a Literature review chapter, a Research Methods chapter, followed by a Results chapter of the general survey results, three additional Research chapters and the final Discussion and conclusion chapter. Among the three research chapters, two have been published in a peer reviewed journal and the remaining one research chapter has been submitted to a journal for publication. So Pyay Thar is the first author of all the research chapters. The co-authors supervised and contributed at various stages of this PhD study. The co-authors of each of the published papers have agreed to the inclusion of these works in this thesis and signed the University of Melbourne co-author declaration form. The co-authors certify that the primary author, So Pyay Thar has contributed greater than 50% to each paper published and was responsible for the planning and execution of the research, including written preparation for publication. The following research chapters have been included in this thesis and are either published or submitted for publication to a journal;

Chapter 5 (published on 14 January 2021)

Thar, S.P., Farquharson, R. J., Ramilan, T., Coggins, S., and Chen, D. (2021). Recommended Vs Practice: Smallholder fertilizer decisions in central Myanmar. *Agriculture, 11*(1), 65. MDPI AG. Retrieved from http://dx.doi.org/10.3390/agriculture11010065

Chapter 6 (published on 16 November 2020)

Thar, S. P., Ramilan, T., Farquharson, R. J., Pang, A., and Chen, D. (2020). An empirical analysis of the use of agricultural mobile applications among smallholder farmers in Myanmar. *Electronic Journal of Information Systems in Developing Countries, e12159*. Retrieved from https://doi.org/10.1002/isd2.12159

Chapter 7 (submitted for publication and currently under review)

Thar, S.P., Ramilan, T., Farquharson, R., and Chen, D. (2021). Farming system typologies and participatory research for decision support in Myanmar. *Agriculture* (Submitted).

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Special thanks to Dr. David Mcgill, who has taught me to design and build questionnaires using CommCare® for collection of digital survey data. Dr. Alexis Pang, who offered critique, advice and feedback during my candidature and has provided valuable assistance with QGIS to map out the villages for the survey. Sam Coggins for the insightful discussions, sharing ideas and experiences with digital extension research with farmers in India and Myanmar.

I would like to acknowledge the assistance from the local extension officers during my fieldworks. Many thanks to all the farmers who shared their time during the household survey and active participation in the focus group discussions.

Thank you to the Melbourne University Research Scholarship and the Australian Centre for International Agricultural Research (ACIAR) for providing the financial support through Project (SMCN/2014/044).

I would like to dedicate my PhD thesis to my parents; I would not have been where I am without their immense support and dream for me. I hope I made them proud. I also appreciate my sister and my brother for their encouragement and support.

Finally, thank you to my loving husband, Castein who has always been there for me to give me love, support and the extra strength and our son Kian, who has been the light of my life.

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LIST OF ABBREVIATIONS

ACIAR	Australia Centre for International Agricultural Research
ADB	Asian Development Bank
ADW	Agricultural Data Warehouse
App	Application
APSIM	Agricultural Production System Simulator
AUD	Australian Dollar
CAMDT	Climate Agriculture Modelling and Decision Tool
CERES	Crop Environment Resource Synthesis model
DoA	Department of Agriculture
DAR	Department of Agricultural Research
DSSAT	Decision Support System for Technology Transfer
DSSs	Decision Support Systems
DSTs	Decision Support Tools
FAO	Food and Agriculture Organization
FARMSCAPE	Farmers', Advisers', Researchers', Monitoring, Simulation, Communication and Performance Evaluation program
FGD	Focus Group Discussion
GDP	Gross Domestic Product
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRDC	Grains Research and Development Corporation
ha	hectare
ICT	Information and Communication Technology
IFDC	International Fertilizer Development Centre
IRRI	International Rice Research Institute
IRRI-CM	International Rice Research Institute - Crop Manager
IS	Information System
K	Potassium
LIFT	Livelihood and Food Security Trust Fund
MIMU	Myanmar Information Management Unit
MMK	Myanmar Kyats
MOALI	Ministry of Agriculture, Livestock and Irrigation
MRR	Marginal Rate of Return
N	Nitrogen
NGOs	Non-government Organizations
P	Phosphorus
PA	Precision Agriculture
PI	Panicle Initiation
ROI	Return on Investment
SSCM	Site-specific Crop Management
UDP	Urea Deep Placement
UN	United Nations
USD	US Dollar
VRA	Variable Rate Application
WNMM	Water and Nitrogen Management Model
YAU	Yezin Agricultural University

Chapter 1
Introduction

1.1 Background

The world population is expected to increase from 7.7 billion in 2019 to 9.7 billion in 2050 (26%) (United Nation, 2019) , implying a continuing need to raise the overall food production especially in developing countries where production is required to be doubled (FAO, 2009). Myanmar is an agricultural country with abundant natural resources with substantial potential for development. The agricultural sector plays a vital role in the country's economy, contributing 38% of the country's GDP accounting for 25-30% of total export earnings and employing more than 70% of the labor force (FAO, 2020).

Agriculture in Myanmar has a high potential for development given the abundant land and water resources of the country. According to the Asian Development Bank (ADB, 2013), Myanmar has 67.6 million hectares of land of which 12.8 million hectares is cultivated land with significant potential to bring new land into production by nearly 50 percent. It also has a relatively high land/population ratio, 0.43 ha/person compared to 0.06 ha/person in Bangladesh (Haggblade et al., 2014) and half the arable land is still fallow (Myanmar Department of Settlement and Land Records, 2012). The water resources in Myanmar also offer a significant agricultural advantage, with an annual renewable fresh water of 19,000 cubic meters per capita which is about 30 times higher than the levels available in Bangladesh, 16 times that of India, 9, 6 and 5 times that of China, Thailand and Vietnam respectively (ADB, 2013). However, the effective utilization of the water resources is less than 10% (AQUASTAT, 2012). Despite its important role in the economy and the rich natural recourses, agricultural productivity in Myanmar is low and farm profits are amongst the lowest in Asia (Findlay et al., 2015).

With the growing demand for food and fiber, depletion of soil fertility and emerging concerns over the environmental implications of agricultural intensification, different agriculture technologies have been developed to make a substantial impact on yield. Improved fertilizer management has contributed to past increases in crop yields (Hirel et al., 2011), being responsible for 30 to 60% of historical yield improvement (WorldBank, 2017). According to the World Rice Statistics (2020), the consumption of fertilizer in Myanmar is very low compared to other Asian countries. Many previous studies have reported that the low productivity of crops in Myanmar is due to the limited use of fertilizers by smallholder farmers in Myanmar (Denning et al., 2013; Garcia et al., 1998; Gregory et al., 2014; Maclean et al., 2013; World Bank, 2020). However, other studies have indicated greater fertilizer use, especially of Nitrogen (N) (Mar et al., 2020; Oo and Ekasingh, 2010). These conflicting reports about fertilizer use created unreliability in the Myanmar fertilizer use statistics (Haggblade et al., 2013; Weil, 2017).

Determining the best fertilizer application is challenging, as fertilizer is considered to be a risk-increasing input (Paulson & Babcock, 2010) with widespread problems of over and under applications. Unlike seeds, where high yielding varieties can be easily adopted by farmers, fertilizers are not provided in appropriate quantities when and where needed (Wharton, 1968). Farmers in developed countries tend to over-apply and misuse fertilizers leading to air pollution, degradation of water quality, damage to soil, and fertilizer waste (Deckers & Steines, 2004; Fageria, 2002; Liu et al., 2009), particularly for high-valued agriculture. In contrast, farmers in developing countries often under apply fertilizers, limiting crop yield and quality resulting in potential loss of profit for farmers (Zaman and Schumann, 2006). This uncertainty in the usage of fertilizer remains an important factor in farmer decisions since such decisions are governed by agronomic and ecological concerns but also have economic and social dimensions.

The global 4R Nutrient Stewardship Framework has been developed to guide fertilizer management (Johnston and Bruulsema, 2014). This framework promotes concept of sustainability through the effective use of fertilizer by selecting the "Right Source" and applying this at the "Right Rate", in the "Right Place" and at the "Right Time" to achieve economic, social and environmental goals (Reetz et al., 2015). It is with no doubt that the source and rate of fertilizers are important, but the timing and the place of application also remain equally crucial (Johnston and Bruulsema, 2014). The timing of fertilizer applications can significantly influence yields and profits of rainfed and irrigated rice farms (Saito et al., 2015; Wang et al., 2017). For example, on-farm testing of fertilizer recommendations in Senegal increased irrigated rice yields by 1 to 2.3 Ton/ha and profitability by 216 to 640 USD/ha (compared to farmer practices) (Saito et al., 2015). Much of the observed yield and profit increase was attributed to different fertilizer timing (Saito et al., 2015). Rahman and Zhang (2018) reported that fertilizer placement is one solution for sustainable fertilizer management in Bangladesh and can be utilized by Myanmar smallholder farmers, given the similar socioeconomic and demographic status. Site-specific nutrient management (SSNM), such as urea deep placement (UDP), is a one-time application that allow plants to access N when required (Johnston and Bruulsema, 2014). When making fertilizer decisions, it is necessary to have knowledge of likely crop yield responses to applied nutrients, the supply of nutrient by mineralisation from soil organic sources and the time duration of effects (Dobermann et al., 2003).

Farmers face many uncertainties and risks, such as weather variability and soil quality (Babcock, 1992) as well as unstable market prices, insurance or labour markets (Lamb, 2003). These unpredictable conditions may constrain the more widespread uptake of fertilizer. Farmers make decisions in the presence of such risks and uncertainty. Is there scope to improve the information used as a basis for those decisions?

Recently, "Big Data" has been providing information and opportunities in decision making for more precise management approaches (Bendre et al., 2015; Lokers et al., 2016). Big Data has been utilized to develop software tools allowing increased volumes of data to be captured, stored, manipulated and used in Precision Agriculture (PA) technologies including DSTs to assist farmers in making better-informed decisions (Keogh and Henry, 2016; Wolfert et al., 2017). DSTs are used to help reduce the effect of uncertainties in supporting farmer decision making (Shim et al., 2002), typically by providing recommendations (Gallardo et al., 2020). These tools aim to reduce human errors in decision making and incorporate data to provide information enabling users to make better informed decisions for improved outcomes (Manos et al., 2008; Power, 2002; Zhang et al., 2012). They provide solutions for crop preparation, planning, sowing and harvesting, as well as providing recommendations for different management practices (e.g. seed rates, irrigation, pest and disease remedies, fertilizer application) according to seasonal climate variability (e.g. rainfall and temperature) (Churi et al., 2013). Despite these efforts, there is limited evidence of the acceptability and successful uptake of these tools by farmers (Alvarez and Nuthall, 2006; Kerr, 2004; McCown, 2002; Shtienberg, 2013).

The use of DSTs in agriculture may help farmers access relevant knowledge and information accurately within a short period of time. Therefore, they can be useful in developing countries, such as Myanmar, where information and knowledge sharing are constrained due to the limited agricultural extension officers. However, due to the reported low uptake of currently available fertilizer DSTs, there is a need for solutions or ways to increase the acceptance by farmers. Thus, this study aims to develop a framework to assist farmers with their fertilizer decisions in Myanmar.

1.2 Research aims and objectives

This research was carried out to enhance the understanding of Myanmar farmers' fertilizer decisions and to develop a framework for a mobile-based tool that may be more acceptable to farmers in Myanmar. The thesis also aims to study the actual management of fertilizers and utilization of agricultural mobile apps by smallholder farmers to better understand their decision making, which is crucial in designing and implementing successful interventions.

With these aims the specific objectives of this thesis were to:

1. Address the use, decisions and perception towards fertilizers by Myanmar farmers, test whether the reportedly low levels of fertilizer use by smallholders are generally

true for central Myanmar, and compare the fertilizer application timing against recommended ‘good management practices’

2. Evaluate the socio-economic factors influencing the effective utilization of agricultural mobile apps for farm-based decision support

3. Introduce the concept of a mobile based DST to Myanmar farmers and identify specific farmer groups who have better possibilities and potential to adopt mobile based fertilizer DSTs.

1.3 Research questions and hypotheses

The following research questions were specified:

1. Are the reported data on the low levels of fertilizer use by smallholders generally true in the case of central Myanmar and how their fertilizer application timing practices compare with the recommended ‘good management practices’?

   The following hypothesis was set:

   i. Farmers in central Myanmar fertilizer management is deficient.

2. What are farmers intentions to use agricultural mobile apps for farm decision making and what socio-economic factors influence their use?

   The following hypotheses were set to answer the research questions:

   i. Socio-economic factors are important for the use of agricultural mobile apps and
   ii. Different socio-economic factors may have a causal relationship with the use of agricultural mobile apps.

3. Whether different farm types exhibit significantly different patterns in the intention to adopt mobile based DSTs and what are farmers’ opinion and acceptability towards these tools to assist with fertilizer decisions in Myanmar?

The following hypothesis was set:

i. Different farm types have different opinions towards use of mobile based DSTs for fertilizer management.

1.4 *Approach of the study*

This research thesis was conducted in association with the project "Management of nutrients for improved profitability and sustainability of crop production in Central Myanmar" which was funded by the Australian Centre for International Agricultural Research (ACIAR, 2016). The main scope of the project was to improve fertilizer management for cereal crops with the objective of reducing poverty and improving food security. The project comprised of two components: bio-physical and socioeconomics. This thesis assisted in the socioeconomic component of the project while contributing to the overall project goals.

Fertilizer yield response trials were developed in 3 Townships; Tatkon and Zeyarthiri located in the central dry zone and Taungoo located in the upper Bago region of Myanmar. Bio-economic models and crop simulation model, Water and Nutrient Management Model (WNMM) were developed by the project.

This research thesis acts as a feasibility study with in-depth participation of farmers to enhance the understanding of the fertilizer management and farmer decisions and to evaluate the acceptability of mobile-based fertilizer DSTs. Primary data was collected by conducting a household survey, interviewing 600 farmers from May to July 2018. Ten villages from each of the project selected townships, a total of 30 villages were chosen for detailed study. The household survey was conducted using a digital data collection platform, CommCare® (Flaming et al., 2016). Statistical analysis was conducted using R and R Studio.

Probit regression model was employed to answer research question 2 evaluating the socio-economic factors influencing the use of agricultural apps mobile apps. Typology Analysis (Gorton et al., 2008; Kobrich et al., 2003) was used to address research question 3 to create different farm household types based on socio-economic characteristics which underlie the adoption of mobile based fertilizer DSTs. Six different farm household types developed and focus group discussions (FGDs) were conducted with each type in January 2020. The FGDs were used to address the last objective as they provided the farmers with the opportunity to be involved and for researchers to better understand farmer beliefs and attitudes towards mobile-based fertilizer DSTs. This allowed implementation of user (farmer) suggestions and opinions in the system design. This information is important in developing a framework for a fertilizer DST according to the needs of farmers that could overcome past barriers to adoption of DSTs. Secondary data were reviewed from relevant reports, both published and unpublished, and collected from government departments, non-government organizations (NGOs), village authorities and projects.

1.5 Thesis outline

This thesis is with publications and contains eight chapters.

CHAPTER 1. Introduction. This chapter includes the background, research aims, research questions and hypotheses. This chapter also contains the brief overview of the approach used to answer the research questions and presents the conceptual framework and the outline of the thesis.

CHAPTER 2. Literature Review. This chapter expands on the background presented in Chapter 1 and is divided into two parts. In Part 1, a general overview of fertilizers in Myanmar is described. Part 2 consists of a systematic literature review on fertilizer DSTs including how farmers makes fertilizer decisions with respect to economics and risks and whether this information is considered in current DSTs, the current DSTs for fertilizer management and their adoption by farmers and discuss the future prospects for DSTs uptake. Based on the review of the literature, the research gaps are identified.

CHAPTER 3. Research Methods. In this chapter, the study area, the process of the household survey and the Focus group discussion (FGD) are outlined. The process of the household survey includes the sampling procedures such as village selection, sample size determination and farmer/household selection. Also included in this chapter are the methods used in the survey including the use of a mobile data collection tool, CommCare®, and shares in-field experiences in design and implementation of this digital data collection tool to capture data in complex farming systems in central Myanmar. The protocol of conducting the FGD with different farm types is also described. Ethical approval for the study was obtained from the research ethics committee of the University of Melbourne (Household survey - Ethics ID: 1851136, FGD - Ethics ID: 1956105.2).

CHAPTER 4. Survey Results. This chapter contains the general results from the household survey including the socio-economic characteristics of farmers such as age, farming experience, household size, off-farm activities, land and livestock ownership, soil types and the type of crops cultivated in the study area.

CHAPTER 5. Recommended Vs Practice: Smallholder fertilizer decisions in central Myanmar: This chapter addresses the first research question of the thesis. The study demonstrated that smallholders were using both Urea and Compound fertilizer for cereal crops. Among the surveyed rice farmers, the average fertilizer applied was much higher than previously reported national average fertilizer rates while the majority of the surveyed maize farmers were found to be applying less than the national recommended rates. With respect to timing, nearly half of the surveyed smallholders were not applying Nitrogen at the estimated panicle initiation stage, which is crucial to increase yield, and the majority (82%) of smallholders were applying Phosphorus, throughout the growth stages when earlier applications are desirable.

This chapter has been published.

Thar, S.P., Farquharson, R. J., Ramilan, T., Coggins, S., and Chen, D. (2021). Recommended Vs Practice: Smallholder fertilizer decisions in central Myanmar. *Agriculture, 11*(1), 65. MDPI AG. Retrieved from http://dx.doi.org/10.3390/agriculture11010065.

The tables and figures numbers have been formatted to be consistent throughout the thesis and the currency unit is expressed in USD as required by the journal while the rest of the thesis is in AUD.

CHAPTER 6. An empirical analysis of the use of agricultural mobile applications among smallholder farmers in Myanmar: This chapter addresses the second research question. The study found that smallholder farmers in Myanmar were optimistic and positive towards agricultural apps although there were many barriers for effective utilization. A Probit analysis from the study indicated that when introducing mobile-based tools, focus should be given to younger, more educated farmers growing more specialized crops. Most surveyed farmers were familiar with information received through Facebook groups. Incorporating useful information and functions from an agricultural mobile app to a Facebook Page could have a more useful and sustainable impact, at the same time eliminating the issues such as lack of awareness, lack of use and long-term servicing and sustainability.

This chapter has been published.

Thar, S. P., Ramilan, T., Farquharson, R. J., Pang, A., and Chen, D. (2020). An empirical analysis of the use of agricultural mobile applications among smallholder farmers in Myanmar. *Electronic Journal of Information Systems in Developing Countries, e12159*. Retrieved from https://doi.org/10.1002/isd2.12159.

The tables and figures numbers have been formatted to be consistent throughout the thesis and the currency unit is expressed in USD as required by the journal while the rest of the thesis is in AUD.

CHAPTER 7. Farming system typologies and participatory research for decision support in Myanmar: This chapter draws upon chapter 6, further distinguishing specific farm types to target as potential adopters of a mobile-based DST for fertilizer management and answers the final research question. Participatory research through FGDs provided evidence that farmers belonging to one type considered that DSTs could be useful in gaining more information and knowledge. Farmers who were interested in the technology indicated that discussion groups are better tools for learning and preferred a learning-based tool rather than a prescriptive tool. Farmers expressed preferences for video clips and infographics integrated into existing digital platforms such as social media and currently available agricultural apps. Integrating participatory research frameworks with typology identification is potentially valuable in assessing new technologies and may have a beneficial role in direct interactions with smallholders.

This chapter has been submitted to *Agriculture* for publication. The tables and figures numbers have been formatted to be consistent throughout the thesis and the currency unit is expressed in USD as required by the journal while the rest of the thesis is in AUD.

CHAPTER 8. Discussion and conclusions. This chapter presents the synthesis of the key findings and contribution from Chapters 5, 6 and 7 and discusses the future research directions and implication of research outcomes.

The conceptual framework of the thesis is presented in Figure 1. The overall outcome of this thesis is a better understanding of Myanmar farmers' fertilizer use and management decisions which is crucial in designing and implementing successful interventions, as well as farmers use of agricultural mobile apps for farm decision making. This research will make an important contribution to further research on information system (IS) and decision support system (DSS) research by bridging the information gap between agricultural app developers and farmers, and will assist international, private and public sector organizations in developing and scaling up agricultural mobile apps to be effectively utilized by farmers.

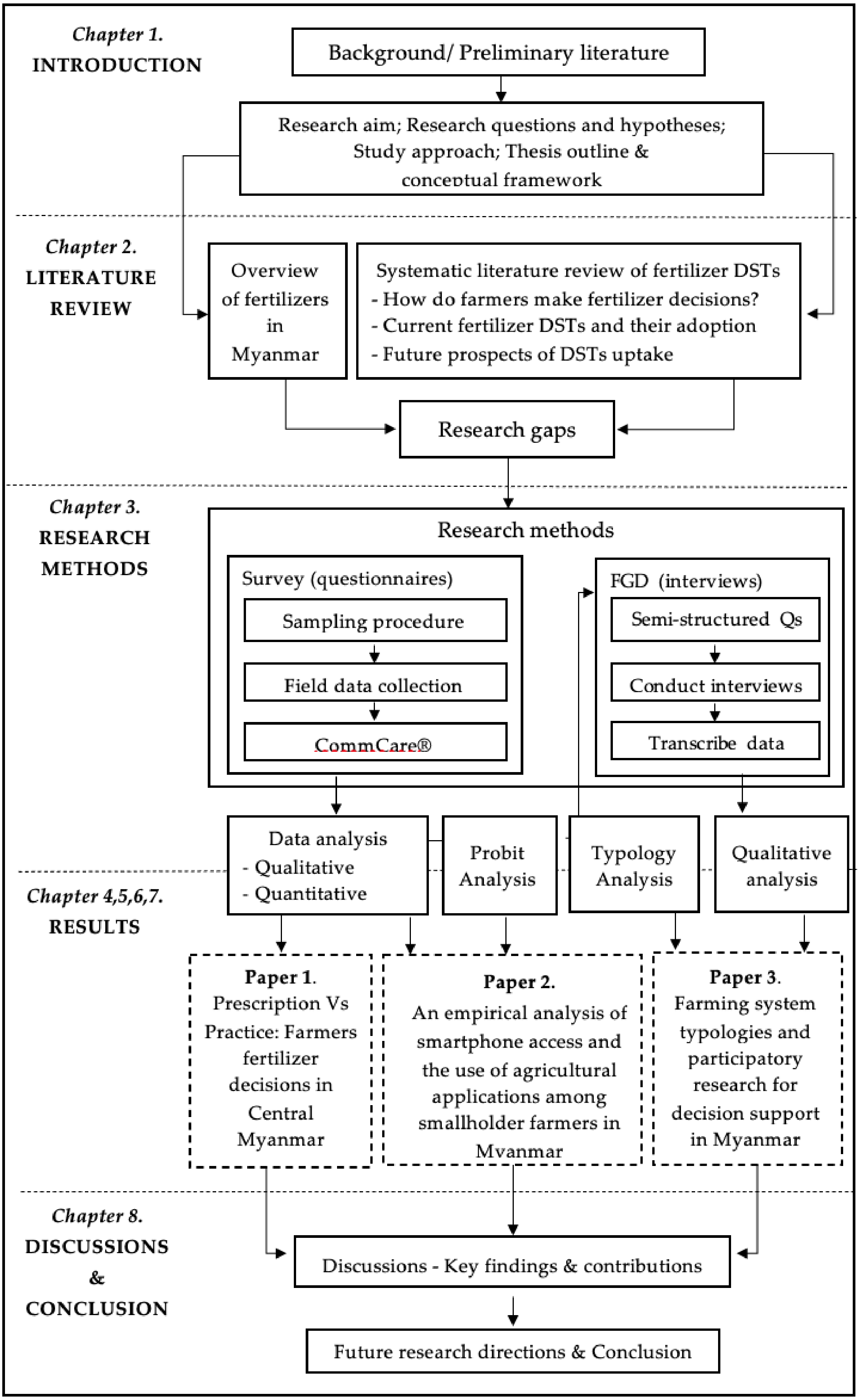

Figure 1. Conceptual framework of thesis

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Chapter 2
Literature Review

In this chapter, a general overview of fertilizers in Myanmar is described followed by a systematic literature review on fertilizer DSTs. Based on the review of the literature, the research gaps are identified.

2.1 General overview of fertilizers in Myanmar

Fertilizers were first introduced to the Myanmar agricultural sector in 1956. In 1960, during the Green Revolution, new plant varieties plus modern agricultural technologies such as utilization of fertilizers along with policies supporting price and investments in seed technology, irrigation, roads and extension were the main factor to boost agricultural production (Hazell, 2009). The widespread use of fertilizer did not take place in Myanmar until 1978 when the government subsidized the prices of fertilizers to encourage use (Lwin et al., 2014). Hence, the subsidized supplies of farm inputs, particularly fertilizer, were not able to meet the demands of the country. The subsidies were completely removed in 2002 when the economy transitioned from state controlled to liberalized. The government imposed tariffs on imports of agricultural inputs leading to the expansion of the private sector to take over the fertilizer market creating a rapid increase in fertilizer prices (Lwin et al., 2014). In October 2002, the Fertilizer Law (Myanmar State Peace and Development Council, 2002)was established with basic legal and regulatory provisions and guidelines. The main objectives of the Law were to:

1. Enable supporting the development of agricultural sector which is the basic economy of the State
2. Enable supervision and systematic control of the fertilizer business
3. Enable growers to use fertilizer of quality in conformity with the specifications
4. Support the conservation of soil and environment by utilizing suitable fertilizer
5. Enable carrying out of educative and research works extensively for the systematic utilization of fertilizer by the agriculturalist and
6. Cooperate with government departments and organizations, international organizations and local and foreign non-governmental organizations regarding fertilizer business.

Amendments to the Fertilizer Law were made in 2015 to address the key elements typical of fertilizer legislation and regulations in the market-oriented fertilizer industry (MOAI, 2015). These included guidelines for fertilizer trade, registration and licensing, and quality control. In general, the Law has been effective in stimulating private sector investment and protecting the interests of Myanmar farmers. However, some implementing regulations are deficient in terms of completeness and clarity based upon international standards (IFDC, 2018). The timeline history of fertilizer in Myanmar is described in
Figure 2.

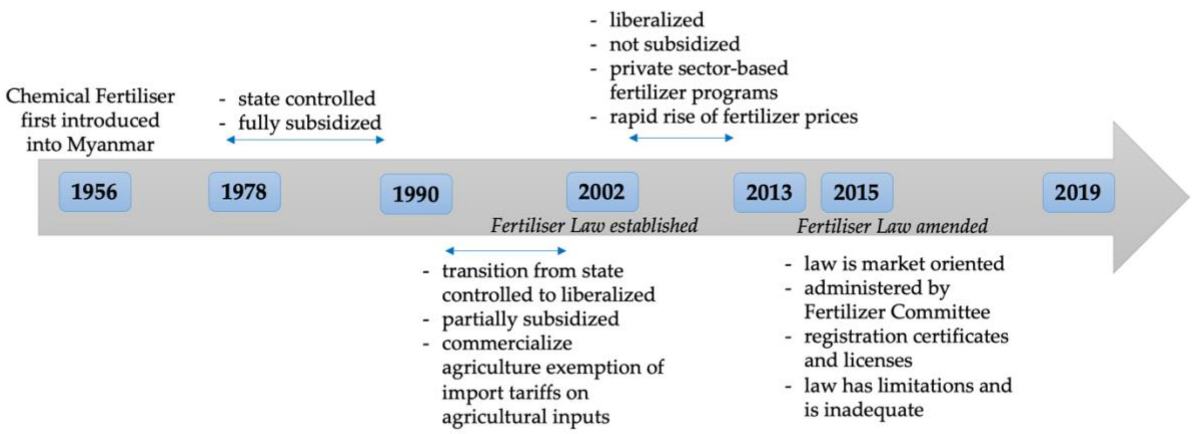

Figure 2. The timeline of the history of fertilizer in Myanmar

Since the removal of government subsidies in 2002, sharp rises in the domestic fertilizer prices have limited the use of fertilizer by smallholder farmers in Myanmar According to the 2016 World Bank database, the use of fertilizer in Myanmar is estimated at 17.9 kg/ha of arable land which is low compared to neighboring countries such as 289 kg/ha in Bangladesh, 503 kg/ha in China, 166 kg/ha in India, 162 kg/ha in Thailand and 430 kg/ha in Vietnam (World Bank, 2021). The World Rice Statistics (2020) has also reported the long history of low fertilizer (NPK) consumption in Myanmar compared to other Asian countries (Figure 3).

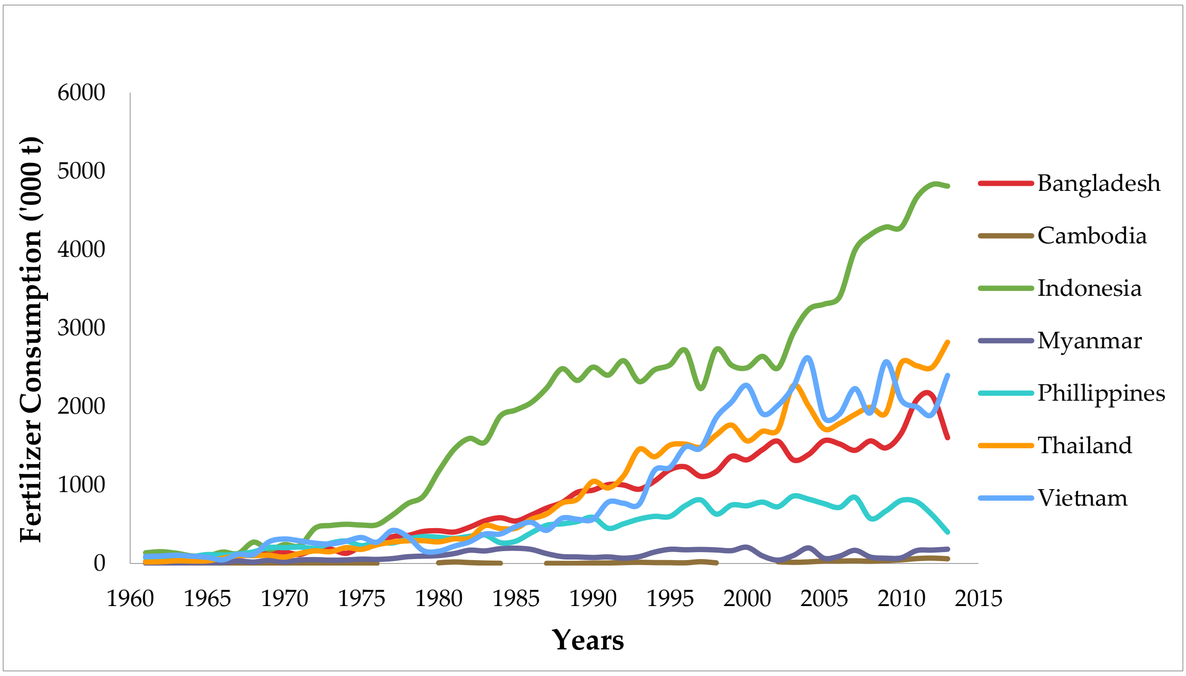

Figure 3. Fertilizer consumption by country (World Rice Statistics, 2020)

Many reports have further documented low use of fertilizer by smallholders in Myanmar (Table 1). A household survey conducted by Stuart et al. (2016) in Bago observed the uncertainty in fertilizer decisions of farmers and suggested that N application rates were one of the reasons for the rice yield gap. In Myanmar, most fertilizer decisions are made based on observations and advice of other farmers in the village (LIFT, 2015). A survey by the International Fertilizer Development Centre, IFDC (2015) stated that Myanmar farmers have strong demand for fertilizer but they have very limited understanding of the correct balance between plant nutrients and maintaining soil fertility, with restricted access to affordable credit.

The aggregate country statistics indicating the low fertilizer use have led to calls for Myanmar farmers to increase fertilizer use. However, there are concerns over the national data quality with very limited representative survey data (Haggblade et al., 2013; Weil, 2017).

Table 1. Reported fertilizer product and element application rates in Myanmar

Reported Rates		References
Kg Product/ha	**Kg N/ha**	
33	5 kg NPK/ha	Maclean et al. (2013); Rice Almanac (2013)
48	22	FAOSTAT (2018)
56 – 71	36 – 44	Gregory et al. (2014)
59	27	Denning et al. (2013); Garcia et al. (1998)
76	35	Naing et al. (2008)
115	53 (15 kg P/ha, 3 kg K/ha)	LIFT (2016)

2.2 *Fertilizer decision support tools (DSTs)*

The global 4R Nutrient Stewardship Framework promotes the effective use of fertilizer by selecting the "Right Source" and applying this at the "Right Rate", in the "Right Place" and at the "Right Time" to achieve economic, social and environmental goals (Johnston and Bruulsema, 2014). Many types of DSTs have been developed based on this framework to support farmers in making better-informed fertilizer management decisions (Keogh and Henry, 2016; Wolfert et al., 2017).

DSTs are used to help reduce the risk of uncertainties in supporting farmer decision making (Shim et al., 2002) typically by providing recommendations (Gallardo et al., 2020). Based on the individual data entered, these tools aim to provide site specific information which users can consider in making decisions for improved outcome (Manos et al., 2008; Power, 2002; Zhang et al., 2012). They provide solutions for crop preparation and planning, sowing and harvesting, as well as providing recommendation for different management practices (e.g. seed rates, irrigation, pest and disease remedies, fertilizer application) according to seasonal climate variability (e.g. rainfall and temperature) (Churi et al., 2013). Despite these efforts, there is limited evidence of the acceptability and successful uptake of these tools by farmers (Alvarez and Nuthall, 2006; Kerr, 2004; McCown, 2002b; Shtienberg, 2013).

The use of DSTs in agriculture may help farmers access the relevant knowledge and information accurately within a short time period. Therefore, it can be useful in developing countries such as Myanmar where site-specific information is important to avoid misleading recommendations and where information and knowledge sharing are constrained due to the limited agricultural extension officers. But the reported low uptake of DSTs by farmers remains a challenge and it is important to consider how farmers make fertilizer decisions with respect to economics and risks and whether this information is considered in the current fertilizer DSTs.

2.3 How do farmers make fertilizer decisions?

Fertilizer decisions are influenced by several factors including human capital (education, extension), financial capital (income, credit), and input-output prices, as well as availability of basic services (infrastructure, quality controls, information and government policies) and the biophysical environment (Yanggen et al., 1998) . Consideration of how farmers make decisions is important when identifying the major reasons for underutilization of technology by farmers (Davis et al., 1989; Putler and Zilberman, 1988). Edwards-Jones (2006) described six important factors influencing farmer decisions: socio-demographics of the farmer, psychological makeup of the farmer, farm household characteristics, farm business structure, the wider social milieu and the characteristics of the innovation to be adopted. Vogt (2017) assessed the economic impact of using precision agriculture technologies such as Decision Support Systems (DSSs) and DSTs and addressed the main factors that can influence the net economic factors. An understanding of farmer decision-making processes allows more accurate predictions of farmer behavior (Gillmor, 1986; Williams, 1958). Keen (1987) stated that understanding "how decisions get made" is a strength of a decision support system.

An important aspect in farmer decision making is the economic dimension (Anderson and Hardaker, 1979; Anderson et al., 1977; Roumasset, 1976). Many authors have considered risk

(Backus et al., 1997; Harwood et al., 1999; Roosen and Hennessy, 2003), risk analysis (Anderson and Hardaker, 1979; Hardaker and Lien, 2007) and risk in utility analysis (Dillon, 1971a), uncertainty and decisions in adopting new technology (Feder, 1980; Marra et al., 2003), processes of adaptation in farm decision making (Robert et al., 2016), managerial decision making (Dillon, 1971b; Samuelson and Marks, 2015) and approaches such as the use of intuition (Nuthall and Old, 2018) in making real-life decisions (Gladwin, 1980). The presence of risk and risk aversion by decision makers have been used to describe the differences in the adoption rates of modern technologies as well as the amounts of inputs used (Feder, 1980). Therefore, accounting for risk in farm decision making is important (Backus et al., 1997) and can be considered in the development of a DST (Monjardino et al., 2015).

The most influential factor when making fertilizer decisions for farmers include potential profit improvement to maximize financial returns (Kelly, 2006). Studies have discussed the economics of optimum fertilizer inputs (Babcock, 1992; Godden and Helyar, 1980; Kennedy, 1981; Lanzer and Paris, 1981; Neeteson and Wadman, 1987; Roumasset, 1976). Economic principles are important in making sound decisions about farm-level management of N (Pannell, 2017). Farmers are more aware of variability in benefits compared to variability in yields (CIMMYT, 1988). Feder et al. (1985) asserted that there is a higher chance of farmers adopting a new technology if a more profitable outcome can be obtained compared to current practices. Therefore, in using DSTs for farmer decisions, the benefits must exceed costs for farmers. Apart from this, a further question is “how much more profitable it needs to be to generate widespread adoption?” (Farquharson, 2006).

Drawing on standard production economic theory (Doll and Orazem, 1984), a recommendation should consider the likely return on investment (ROI) in a new technology and examine the likely minimum ROI for a technology to be adopted by farmers (Farquharson, 2006). CIMMYT (1988) suggested that a ROI should be at least twice the cost of capital, or a 50-100% minimum rate for smallholder farmers in developing countries. A change in technology with a marginal rate of return (MMR) of 100% is more likely to be appealing compared to MRR of less than 50% (Erenstein, 2009). A minimum, or hurdle, MRR can be considered necessary before a recommendation is made within a DST. However, farmer decisions are not only influenced by profits but by many other criteria (Wallace and Moss, 2002). Farmers are unlikely to make profit maximizing fertilizer decisions without other information about risks and liquidity (Kavoi et al., 2014).

When deciding fertilizer application rates and scheduling, most farmers depend on experience and guesswork. Current farmers approach regarding fertilizer decisions include:

- using visual observation of plants (Fageria, 1992) including the use of leaf colour charts (Ahmad et al., 2016; Dobermann et al., 2004)
- learning from neighbouring farmers (Gathiaka, 2012; Munshi, 2004)
- reading labels and following instructions on package (Mustapha and Said, 2016)
- hearing from advisors that use target yield approach (Herridge, 2011; Ren, 2000) or using tools based on water use efficiency (French and Schultz, 1984) to set a target yield
- soil testing/ use deep soil N pre-sowing measurements or plant testing (Fageria, 1992; Fixen, 2005).

However, the above approaches come with limitations as described in Table 2.

Many contemporary agricultural technologies focus on quantifying soil N for precise application of fertilizers. Variable rate application (VRA) is a site-specific crop management (SSCM) method of applying inputs such as seed, fertilizers and chemicals in varying amounts based on specific sites (Kuhar, 1997). This method aims to ensure efficient application of inputs to better match the changing requirements of the soil and crop which save resources while maximizing profit with lesser impact on the environment (Grisso et al., 2011). Anderson (1975) noted that the level of net benefit is small when management practices are varied within the optimal region because the economic profit functions are relatively flat. Pannell (2006) described the economic pay off functions for many agricultural inputs as being relatively flat around the optimum. The implication of flat rate pay-off functions is that it is unnecessary to be precise about the optimal rate of an input such as fertilizer at the top of the input-profit response curve. This allows for flexibility for farmers to adjust rates by considering other factors such as risk, labor, soil type, climate, and availability of finance or environmental impacts. Farquharson (2006) accommodated the flatness of response issue by requiring a minimum target ROI (or MRR) for cereal fertilizer decisions.

Table 2. Limitations to alternative approaches to fertilizer decision making

Farmer approaches	Limitation of techniques
Visual observation of plants (Fageria, 1992)	- Can easily be mistaken with pest and disease attacks or abnormal weather effects on plant growth rather than nutrient deficiency - Requires farmers to have wide field experience for accurate diagnosis - Yield losses may have already begun once the visual symptoms become apparent (Fixen, 2005)
Learn from neighbouring farmers (Gathiaka, 2012; Munshi, 2004)	- Cannot always be the same situation - Variation from field to field in soil type, texture, and moisture/nutrient content
Read labels and following instructions on package (Mustapha and Said, 2016)	- Farmers cannot be certain about the effectiveness of purchased fertilizer and the level of soil-available fertilizer (Paulson and Babcock, 2010)
Hear from advisors that use target yield approach (Herridge, 2011) or use tools based on water use efficiency (French and Schultz, 1984) to set a target yield	- Target yield and protein content are specified by individual farmers, the required N is estimated as the 'demand' and the soil N 'supply' is calculated, with the difference being the amount to apply - Does not incorporate an economic perspective - Does not estimate N mineralization
Soil/plant testing (Fageria, 1992; Fixen, 2005)	- More reliable diagnostic methods involve high cost and complex procedures, as well as the acquisition and timely interpretation of the information provided (Krishna, 2002)

In the face of large uncertainties John Maynard Keynes said that "it is better to be approximately right than precisely wrong" (Keynes, 1936). In designing a DST, although it may be possible to develop very precise recommendations, the result may be meaningless if the economic response function is relatively flat over a range of fertilizer input levels. In such cases, it would be better to have approximate solutions from a simpler tool which better represents and relates to farmer decision making. Farmers may react to uncertainties by adopting a level of input in the suboptimal region (suboptimal to maximum economic profits) to avoid irrecoverable damage or loss (Jardine, 1975). A VRA can be:

1. map based (using electronic maps/ prescription maps to adjust the application rates of inputs) (Forouzanmehr and Loghavi, 2012), and/or
2. sensor based (using real-time sensors that can control site specific field operations electronically) (Cho et al., 2002; Ehlert et al., 2004).

Both systems have benefits and drawbacks and the best approach will be to combine these two systems (Nittel, 2009; Thessler et al., 2011). An automated fertilizer applicator which calculates the optimal quantity and spread pattern of fertilizer was built using GPS technology, decision support, real time sensors and Bluetooth technology for tree farming (Cugati et al., 2003). He et al. (2011) developed an integrated optimal fertilization DSS using wireless sensors to measure real time soil and weather data, conductivity, pH values and Geographic Information System (GIS) analysis servers. By integrating modern technologies such as GIS, GNSS (Global Navigation Satellite System), ICT (Information & Communication Technologies) in precision farming, spatial predictions of crop yield response to fertilizer can be generated based on different times and locations and also predict the nitrogen use efficiency (Blaes et al., 2016; Zhang and Tillman, 2007). A study by Robertson et al. (2012) suggested that while there is an increase in adoption of VRA by farmers over the years, unpredictable weather conditions still remain a constraint.

Unpredictable weather is an another major reason for many decisions by farmers (Chavas et al., 2010). Fertilizer decisions depend on climate conditions and seasonal climate forecasts (SCF) can be important for farmers when making fertilizer decisions (Nidumolu et al., 2016). SCF can minimise the risks associated with fertilizer applications and have been used for managing agricultural climate risks (Hansen, 2005; Shafiee-Jood et al., 2014). Hammer et al. (2001) and Hansen (2002) outlined potential advantages of predicting climate in agriculture. AgroClimate (www.agroclimate.org), Yield Prophet (Hochman et al., 2009), and Climate Agriculture Modeling and Decision Tool (CAMDT) (Han et al., 2017) are examples of DSTs which have been designed to predict seasonal weather forecasts and provide information for crop growth/yield and disease occurances.

2.4 *Crop models in DSTs for fertilizer management*

A crop model integrates climate, soil, crop and management together to predict crop yield and N requirement (MacCarthy et al., 2017). Many crop models have been developed to provide information for DSTs to support decision-making for fertilizer management (Astover et al., 2006; Zebarth et al., 2009). Some crop models are empirical while others are mechanistic (Jones et al., 2016; Paola et al., 2016). Empirical crop models, also known as functional models or phenomenological models (Addiscott and Wagenet, 1985), are based on empirical functions mainly between environmental factors and yield, and require experimental field data for estimation (Paola et al., 2016). These models are used to develop relationships for forecasting and describing trends. Examples include estimating radiation interception or an indicator of crop biomass or measuring biomass produced per unit of radiation intercepted (Jones et al., 2016). Mechanistic or process-oriented models are based on known or hypothesized control of physical, chemical, and biological processes occurring in crop or animal production systems (Jones et al., 2016; Keating et al., 2003; Paola et al., 2016). These models are developed to provide detailed explanations of the soil-plant-atmosphere system and require substantial information (Big Data) input. Big Data in agriculture refers to "the huge amount of data generated in agricultural practice and management" (Bendre et al., 2015). The concept of Big Data in agriculture is the capability to extract information to produce "insights" which has been economically and technically impossible in the past (Sonka, 2015). Example includes describing instant changes in plant processes (Basso et al., 2013). Building on previous comparison studies of crop models, Estes et al. (2013) compared the suitability and predicts the productivity of both empirical and mechanistic models and their results suggested that empirical models can achieve the same or better accuracy as mechanistic models.

Some widely used models include CERES (Crop Environment Resource Synthesis model) (Godwin et al., 1990; Singh et al., 2008), DSSAT (Decision Support System for Technology Transfer) (Jones et al., 2003), APSIM (Agricultural Production System Simulator) (Keating et al., 2003; McCown et al., 1996), WNMM (Water and Nutrient Management Model) (Li and Chen, 2010; Li et al., 2007), and AquaCrop Model (Foster et al., 2017). A detailed historical view of agricultural systems modelling was described by Jones et al. (2016). They focused on bio-physical based models but also described economic models and factors influencing the development of these models. An extended list of crop models used in DSTs to support decision-making in fertilizer management is provided in Table 3.

Some models have weakness with respect to weather variability and change in management which limit future predictions (MacCarthy et al., 2017) and some models lack incorporation of economic perspective which limit future adoptions (Fixen, 2005) . Akponikpe et al. (2014) noted that APSIM and DSSAT were the most promising crop models, but that improvements were still required. However, it is challenging for farmers to utilize crop models as they require intermediaries such as farm consultants or advisers to explain the crop simulations applied to farmer fields (Carberry et al., 2002) and this led to the development of web based DSTs (e.g. Yield Prophet). A conceptual diagram of a crop model-based fertilizer DST is shown in Figure 4.

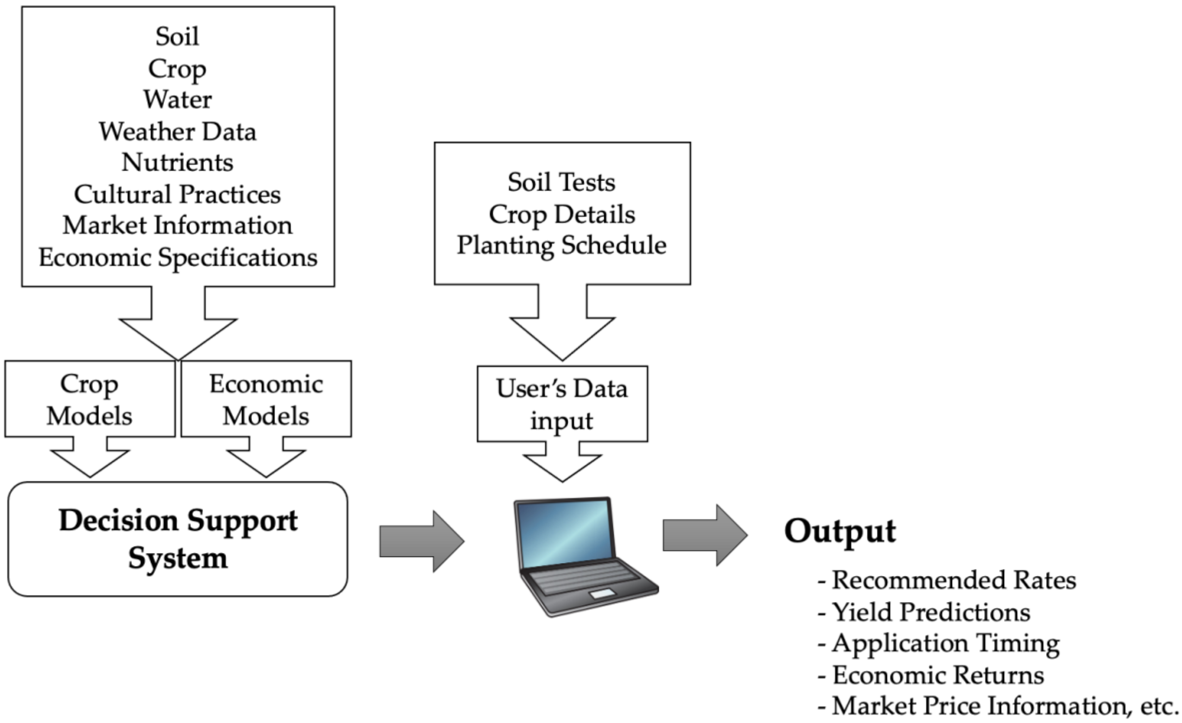

Figure 4. Conceptual framework of a DST

Table 3. Crop models used for fertilizer management

Model	Description	Source
WATBAL	- Water Balance model - useful in the evaluation of weather constraints and access hydrological effects of land use changes	McCown (1973)
EPIC	- Erosion Productivity Impact Calculator - determine optimal management strategies - includes runoff of nitrate, organic N transport by sediment, leaching, upward nitrate movement by soil evaporation, denitrification, immobilization, mineralization, crop uptake, rainfall contribution, fertilizer application, and fixation and economic components	Williams et al. (1983)
NCSOIL	- Nitrogen Carbon Soil model - sub model of Nitrogen Tillage Residue Management - computes short-term dynamic of C and N	Molina et al. (1983)
PERFECT	- Productivity, Erosion, Runoff Functions, to Evaluate Conservation Techniques - provide long term estimates of erosion, water, drainage, crop growth and yield - a fully dynamic model which is improved from previous models - incorporates interactions between management strategies, crop residue and hydrological processes	Littleboy et al. (1989)
NLEP	- Nitrate Leaching Economic Analysis Package model - determine potential nitrate leaching and evaluate N management practices - provides projected N budgets, potential loss and off-site effects of N by leaching and economic impacts - designed for use by farmers, extension officer and action agencies	Shaffer et al. (1991)
NuMas	- Nutrient Management Advisory System - measures effects of soil acidity on crop productivity	LaMaran and Leatherman (1992)
CENTURY	- site-specific model based on interactions among soil-plant-climate - simulate the dynamics of grassland systems, agricultural crop systems, forest systems, and savanna systems - consists of a sub model for soil organic matter (SOM)	Parton and Rasmussen (1994)
SUNDIAL	- Simulation of Nitrogen Dynamics In Arable Land - dynamic computer model of N turnover in the crop/soil system - fertilizer recommendation system SUNDIAL-FRS developed to provide field by field fertilizer recommendations	Smith et al. (1996)
AZODYN	- determine optimal dates for split fertilizer applications - simulates N losses linked to environment and the effects of N stress and water deficiency on the availability of soil N, plant growth, crop N uptake and grain yield and N content	Jeuffroy and Recous (1999)
CERES	- Crop Environment Resource Synthesis model - integrates soil water, soil N and crop growth and yield - the output provides the biomass N content and information on soil reserves of available water and N - available for wheat, maize, sorghum, pearl millet, barley and rice	Godwin et al. (1990); Singh et al. (1993)
CROPGRO	- model for grain legumes - contains SOYGRO model for soybean and PNUTGRO for peanut/groundnut and BEANGRO for bean	Singh et al. (1994); Wilkerson et al. (1983)
DSSAT	- Decision Support System for Technology Transfer - suite of cropping system models (CERES + CROPGRO + CENTURY) - a more dynamic type of crop model which allows users to simulate different crop management over a period of years	Jones et al. (2003)
APSIM	- Agricultural Production System Simulator - based on CERES, EPIC, PERFECT - important feature of APSIM is *APSData* which provides an economics module of cost and price information	Keating et al. (2003); McCown et al. (1996)
WNMM	- Water and Nutrient Management Model - modifies the concepts and components from widely used models - stimulates soil N transformations and greenhouse gas emission	Li et al. (2007)
AquaCrop-OS	- AquaCrop Model developed by FAO - simulates soil water balance and crop growth - quantify crop yield response to water - for herbaceous crop types - can combine with other models for integrated water policy analysis	Foster et al. (2017)

Parameters for soils, crop, water, climate, weather, nutrient inputs, cultural practices, market information, economic specifications are integrated into a DST through crop models and economic models (MacCarthy et al., 2017). DST users are required to provide data for soils and crops to generate an output leading to recommendations for fertilizer use to increase production and reduce fertilizer costs while protecting the environment (Pal and Arora, 2009). DSTs can, therefore, be used to estimate yield target and N demand. Outcomes from these tools can assist farmers in making decisions about the amount of fertilizer to apply based on soil type, and time and frequency of application according to the weather and type of crop cultivated and current soil conditions (Aubert et al., 2012).

Yield Prophet DST offers individual growers the ability to assess crop yields that can be obtained based on different rates of N application across soil types under various weather conditions for individual field (Hunt et al., 2006). The International Rice Research Institute (IRRI) developed the Crop Manager DST which provides location-specific nutrient management guidelines to rice, maize, and wheat farmers in Asia (IRRI 2016).

Field research from 647 trials showed an average yield increase of 370 kg following the recommended guidelines of the Crop Manager DST (IRRI, 2016). Crop Manager, however, was limited to decisions for only a few crops (rice, maize, and wheat). Moreover, the potential yield increase takes no account of the economics of adding extra fertilizer. Fixen (2005) suggested inclusion of a budget analysis software integrating nutrient use decisions, yield potential and cost of production to illustrate the role of nutrient management in farm profitability. Currently operational DSTs for fertilizer management which are available to farmers, extension agents, farm advisors, researchers, educators or consultants are listed in Table 4. Sixteen DSTs are listed by model type, delivery mode, and country covering a wide range of crops.

Table 4. Currently available fertilizer DSTs

DST	Category	Mode of delivery	Crops	Country	Source
Yield Prophet	Crop model based (APSIM)	Web based	Wheat, Barley, Canola, Sorghum and Oats	Australia	www.yieldprophet.com.au
DSSAT	Crop model based (DSSAT)	Software	Over 40 crops (grasses, cereals, legumes, vegetables, fruits)	150 countries	https://dssat.net/
IRRI Crop Manager	Empirically based	Web based, Mobile phone	Rice, Maize (under evaluation)	Bangladesh, Indonesia, India, Philippines	www.knowledgebank.irri.org/decision-tools/crop-manager
Smart! Fertilizer Management	SaaS cloud model	Web based	Grasses, Cereals, Legumes, Vegetables, Fruits, Herbs, Flowers	62 countries	www.smart-fertilizer.com
PLANET, MANNER-*NPK*	N/A	Software	Most agricultural and horticultural crops	England, Scotland	www.planet4farmers.co.uk
FarmN	Empirically based	Web based	Grasses, Cereals, Legumes	Denmark	www.farm-n.dk
Haifa Nutri-Net	N/A	Web based Software	Cotton, Maize, Pineapple, Rice, Soybean, Sugar beets, Tobacco	Israel	www.haifa-nutrinet.com
Nutrient Expert	QUEFTS model	Software	Maize, Wheat	Asia, Africa	www.software.ipni.net
N Budget	Empirically based	Excel based	Cereals, Legumes	Australia	Herridge (2017)
AmaizeN	N/A	Software	Corn	New Zealand	www.far.org.nz (Li et al., 2009)
CNRC	Empirically based	Web based	Corn	Iowa, Illinois, Indiana, Missouri and Kansas	www.cnrc.agron.iastate.edu
Corn Split N (U2U DST)	N/A	Web based	Corn	Iowa, Illinois, Indiania, Nebraska	www.splitN.AgClimate4U.org
DSS4Ag	Crop model	Web based	Wheat, Potato	USA	Hoskinson and Hess (1999)
CropSAT	N/A	Web based	Wheat	Sweden, Denmark	www.cropsat.se (Söderström et al., 2017)
CropWat	N/A	Software	Rice, Coconut, Banana, Tea, Vegetables, *Pulses*, *Cotton*, Rubber, Coffee	FAO	https://cropwat.informer.com/8.0/
AzoFert	Crop Model (N balance sheet)	Software	Cereals, industrial crops, vegetables (40 crops)	France	(Machet et al., 2017)

2.5 Adoption of fertilizer DSTs

Adoption is defined as an "innovation-decision process through which an individual (or other decision-making unit) passes from first knowledge of an innovation, to forming an attitude towards the innovation, deciding to adopt or reject the innovation, implementing the new idea, and confirming the innovation decision" (Rogers, 2003). Wilkinson (2011) described adoption as "the process of discovery, decision and action through which each individual goes when taking up a new practice". The adoption of new technology was defined by Anderson and Hardaker (1979) as "different way of doing things down on the farm", such as changing rates, dates and forms of sowing and fertilizer application.

2.5.1 Current level of adoption of different DSTs

DSTs are widely available and have a range of advantages for users, however, there has been little on-going adoption by farmers (Alvarez and Nuthall, 2006; Kerr, 2004; McCown, 2002b; Shtienberg, 2013). It is difficult to measure the use of DSTs for nutrient management, but Table 5 provides a brief information on user numbers for some DSTs.

Some web-based DST are free and do not require registration or subscription to use and hence there is no record of the adoption of such tools. According to the Grains Research and Development Corporation (GRDC), at least 68 computer-based decision support tools have been developed, in Australia alone, for the Australian grain industry to support decisions with regard to climate variability; irrigation and water scheduling; pest, disease and weed management; fertilizer management; variety selection and rotation practices. Among these there are 58 tools providing information on rainfall, variety, disease risk or useful calculations for yield, fertilizer, irrigation or providing sensitivity analyses so that users can obtain information on "what if" conditions. Among these 58 tools, 29% are no longer in use, 9% are in limited use and no longer have support, and 12% are underdeveloped or being upgraded (Muchow, 2011).

Table 5. Level of DST use for fertilizer management

DST		Comments	Source
Yield Prophet	-	800 - 1000 Australian paddocks under review in 2018	C. Sounness, Personal Communication, 23 August 2018
DSSAT	- -	more than 14,000 users including farmers, researchers, extension officers in over 150 countries worldwide This shows the worldwide outreach of DSTs, but the number of users is low for over 150 countries	G. Hoogenboom, Personal Communication, 10 August 2018
IRRI Rice Crop Manager	- -	generated recommendations for about 350,000 farmers from 2015 to 2017 in the Philippines It may appear that the Crop Manager is well received by farmers but considering the 5 million farmers in the Philippines (Phillippine Statistics Authority, 2018), the number remains low.	R. Castillo, Personal Communication, 23 August 2018
SMART fertilizer	-	over 100 subscribers in more than 62 countries since it started in 2014	A. Kaparovsky, Personal Communication, 9 August 2018
PLANET software	- -	18,000 registered users and 4000 registered users of the MANure Nutrient Evaluation Routine (MANNER) software in England/Wales and Scotland. The UK Farm Practice survey results also states that 23% of the farmers used PLANET and another 29% used either MuddyBoots or Farmade, both of which include the PLANET recommendations	L. Sagoo, Personal Communication, 13 August 2018
Nutrient Expert DST	- -	still at the initial stage of scaling out and hence not yet been widely used by farmers has been estimated that less than 10% of farmers in Asia and Africa combined has been exposed to Nutrient Expert	M. Pampolino, Personal Communication, 21 August 2018
Corn Nitrogen Rate Calculator (CNRC)	-	12,780 users; 108,739 page viewers; 18,179 sessions from 113 countries with most users from the United States and 111 users in Australia	J. Sawyer, Personal Communication, 24 August 2018
Corn Split N DST	-	According to a 2016 survey, conducted with Midwest U.S farmers, 56% of farmers and 72% of advisors stated that they will recommend the tool to others	M. Widhalm, Personal Communication, 21 August 2018

2.5.2 Factors affecting the adoption of DSTs

Many studies on adoption have described factors influencing the adoption of new agricultural technologies and practices (Feder and Umali, 1993; Knowler and Bradshaw, 2007; Koundouri et al., 2006). The adoption behavior of farmers for new technology depends on the socio-economic context and time period (Feder et al., 1985).

Lack of user participation in DST development has been shown as the main cause for low uptake by farmers suggesting that the tools are not relevant for growers. The tools may have been developed based on what developers and scientists considered necessary for decision support and not on practical farmer needs (Lynch and Gregor, 2004; McCown, 2002b; Muchow, 2011; Prost et al., 2012; Walker, 2002). Further work has been done to improve the DSTs by incorporating participatory approaches, considering user-centered aspects for successful delivery of the DST to farmers (Antle et al., 2017; Carberry et al., 2004; Jakku and Thorburn, 2010; Lacoste and Powles, 2016; Parker and Sinclair, 2001; Smith et al., 2017; Thorburn et al., 2011; Valls-Donderis et al., 2014; Van Meensel, 2012). Yield Prophet is an example incorporating farmer participation in using a systems approach for decision making as it integrates the FARMSCAPE (Farmers', Advisers', Researchers', Monitoring, Simulation, Communication And Performance Evaluation) program (Carberry et al., 2002; Hochman et al., 2000).

High upfront costs can also limit adoption if finances are unavailable for investment (Pannell et al., 2006), although there are some DSTs that are free of cost (e.g. DSSAT, IRRI-CM). When users must invest time and effort, and sometimes money for registrations, license or soil analysis, to collect information for DSTs, it is important that they benefit financially. A study by Rose et al. (2016) suggests that tools are likely to be trialed and tested by farmers if it is free or if a grant is supporting for purchase.

Human capital such as skills, education, age, farmers personalities and objectives are also factors affecting the adoption of DSTs (Alvarez and Nuthall, 2006; Asfaw and Admassie, 2004; Carayannis and Sagi, 2000; Cox, 1996; Lindblom et al., 2014; Lundström and Lindblom, 2018). According to FAO (2014), the average age of farmers worldwide is 60 years and older farmers are less likely to adopt new technology. A higher level of human capital such as educational and age factors are required for the adoption of DSTs (Carayannis and Sagi, 2000). The next generation of young farmers and the intergenerational change can have an impact on further adoption of DSTs (Foskey, 2005). Nguyen et al. (2007) suggested that DSTs might play a greater role in the future of farmer decision making.

Older farmers may not have sufficient skill or knowledge to use computers and software compared to professional researchers (Cox, 1996). Fear of using computers has constrained the use of computer-based DSTs by farmers (Nguyen et al., 2007). There is a strong need for capacity building in use of models and model development for DSTs for development of effective tools (MacCarthy et al., 2017). However, farmers are now living in the smartphone era (Pongnumkul et al., 2015) and may adopt DSTs based on mobile apps which require less training and learning. With new advances in digital app technologies, decision support apps for agriculture are growing in popularity allowing farmers to immediate access to DSS generated information via smartphones (Lewis et al., 2020).

A study of the use of smartphone technology by European farmers found that 89% of the respondents owned a smartphone and 84% used it for farm management because smartphone applications generated agricultural information with great potential for problem solving (Dehnen-Schmutz et al., 2016). Their study also suggested a global applicability, especially in developing countries where the use of mobile phones among rural smallholders has risen in recent years (Henriques and Knock, 2012). Software application for mobile devices, focusing on the fertilizer and fertilizer management of crops, have been widely developed in recent years (Table 6). However, only a few recommend optimal fertilizer levels (Bueno-Delgado et al., 2016).

Ease of use is considered to be one of the most influential reasons for farmers not using DSTs (Rose et al., 2016). Other studies have highlighted user preferences for simple DSTs (Armstrong et al., 2003; Knight and Mumford, 1994; Nguyen et al., 2007). Farmers have a preference for a “quick and simple” decision approach over a detailed and elaborate approach (Ohlmer et al., 1998). Current fertilizer DSTs require input of many variables, such as location, soil tests, and crop details (e.g., sowing date, crop type, cultivar, and sowing density). Although these factors are necessary for developing an accurate and efficient DST, they require extra effort for farmers and there are multiple constraining factors such as difficulty, inconvenience or expense in collecting the data (Mir and Quadri, 2009). Therefore, DST developers should consider minimizing and simplifying the data required and automate data input by linking data bases.

Table 6. Mobile apps to assist farmers with fertilizer management

Mobile App	Source
Fertilizer Removal by Crop	https://play.google.com/store/apps/details?id=com.agphd.fertilizerremoval
Fertilizer Cost Calculator	https://play.google.com/store/apps/details?id=com.kineticthoughts.agbizapps
NPK	https://play.google.com/store/apps/details?id=com.easy.fertilizer.calculator
MITRA	https://play.google.com/store/apps/details?id=com.sfits.mitra
Fertilizer Calculator	https://play.google.com/store/apps/details?id=in.res.ccari.fertilizercalculator
Crop Fertilizer	https://play.google.com/store/apps/details?id=com.cropsfertilizers
Fertilizer Service	https://play.google.com/store/apps/details?id=de.mcs.amazone.ds
FertiMatch	https://play.google.com/store/apps/details?id=com.hd.haifa_demo
DSS-FS	https://itunes.apple.com/us/app/%20dss-fs-app/id966186614?mt=8
SSCA Fertilizer Blend Calculator	http://www.ssca.ca/index.php/28-last-added-projects/71-ssca-fertilizer-blend-calculator
Organic Fertilizer	https://itunes.apple./nz/app/organic-fertilizer-app/id971290947?mt=8
Rice Doctor	https://play.google.com/store/apps/details?id=com.lucidcentral.mobile.ricedoctor&hl=en
Graincast	https://graincast.io/

DSTs such as Farm N are designed to fit the situation of an average individual farm, requiring minimum input from the user thereby minimizing the complexity of the tool (Jørgensen et al., 2005). In such a case, the validity of the tool is not specific to individual farms. There is a trade-off between simplicity and accuracy of the tools. A study by Bohanec and Bratko (1994) commented that “there is significantly greater simplification at equal loss of accuracy” in the real-world. This trade-off is an important aspect to consider in developing a DST. Jørgensen et al. (2005) emphasized that more data input is required for the results to be more accurate although requiring too much data may restrain the tool from being used. Therefore, tools can be less accurate, but can be very useful if they capture the main characteristics of the systems.

2.6 Prospects of DSTs

DSTs have faced very little on-going adoption as a practical tool mainly because the earlier versions lack user participation as well as insufficient training and technical support (Gallardo et al., 2020). Further work has been done to improve the DSTs by incorporating participatory approaches and considering user-centered aspects. While there have been some success stories (Cain et al., 2003; Carberry et al., 2002; Hochman et al., 2000) with potential prospects, today this effect has not been widely seen. Lindblom et al. (2017) reported that user-centric focus still appears to be minimal and there is a need for active participation by farmers in agricultural research and development processes. Antle et al. (2017) suggested a user-driven approach which defines the end-user prior to the study and develops case studies to understand the particular requirements of users. Their study suggested that users do not want models but prefer transferable information. They proposed an implementation strategy which links a "pre-competitive space" for model development and improvement to a "competitive space" for knowledge product development.

DSTs are evaluated mostly on the basis of developed country (McCown, 2002a). In case of developing countries, although limitations may exist such as data or information on soil type, fertilizer response, or GPS location, or not having access to the complex technology used in PA applications (Carberry et al., 2002; McCown, 2002b), the limited experience suggests that there is a potential. Studies by Meinke et al. (2003) and Gadgil et al. (2002) used crop models to demonstrate the possible management responses to climate forecasts with farmers in India and both studies suggested that it is an effective way to ensure benefit based on climate knowledge. A participatory workshop conducted in Sri Lanka for the construction of a DST also showed promising results for adoption with interest from farmers and policy makers (Cain et al., 2003). Their study addressed the need for multidisciplinary approaches. Carberry et al. (2004) also conducted a workshop with farmers in Zimbabwe using APSIM crop simulations as the basis for discussion and famers found that the simulation results were relevant and credible. Their study concluded that the model applied within an action research framework leads to learning and increased the overall interest of farmers by facilitating a high level of farmer-researcher interaction.

Recently PA technologies have become more available to farmers with the main focus on information support (Mazzetto et al., 2019). As emphasized by Janssen et al. (2017), ICTs are important for next generation models and future DSTs. The current mission of PA is to provide precise information based on Big Data and agricultural data warehouse (ADW) (Ngo et al., 2020). Sarker et al. (2019) reveals that application of Big Data technologies in agriculture is growing but still at low level. Big Data is a large, multidimensional, complex, and distributed data set generated from internet sources, satellites, daily official queries, purchasing behaviors, opinions and social media (Coble et al., 2018). The importance of Big Data in agriculture with respect to Smart Farming was reviewed by Wolfert et al. (2017) and the "Big Data Pillars of Success" Model was proposed to transform PA to decision agriculture (Skinner, 2018). Future efforts can take advantage of the big data collections, i.e. information from various sources, to improve the data layers behind DSTs and improve the integration of knowledges (i.e. modelling) of process interactions to determine productivity and environmental outcomes.

Integration of information technological tools, such as global navigation satellite systems (GNSS), chlorophyll meters, remote sensing of soils and crop canopies, soil electrical conductivity sensors and yield monitors with modern agricultural equipment such as fertilizer applicators, planters and sprayers can facilitate intra-field variable management of crops and soils (Rogovska et al., 2019). There is a greater ability to predict responsiveness of crops to fertilizer by integrating multiple data sources (Venkatalakshmi and Devi, 2014). This aims to deliver precise real-time information of the crop and field conditions to farmers and allowing them to make their own informed decision. Implementing more interactive and visual DST may enable end-users with better understanding and attract potential users (Gutiérrez et al., 2019).

Despite recent advances, farmers still lack rapid and economic means of developing nutriment management plans (Rogovska et al., 2019). Integration of socioeconomic data with geospatial and biophysical information enhances the use ability and scaling up potential of decision support systems (Agrahari and Tripathi, 2012). The previously mentioned economic dimensions in farmers decision making remain an important aspect and a possible factor for adoption. A minimum target ROI of 100% has been suggested in developing recommendations for change in technologies, especially for smallholder farmers in developing countries. The flatness of economic responses at relatively high levels of fertility and crop yields appears to be important, but at low levels of fertilizer use a relatively high hurdle rate of return may offer more assurance to smallholder farmers about borrowing for fertilizer purchases. Stott et al. (2018) reported that the 'Dairy Nitrogen Fertilizer Advisor' (the 'N-Advisor') tool uses marginal analysis to inform farmers about how a range of N applications applied to a particular paddock for a particular grazing rotation add to profits and enables uncertainty associated with the fertilizer investment to be considered. This production and profit information that can be estimated using the N-Advisor has sufficient rigor and relevance to add value to decisions dairy farmers make about applying N.

There are many examples of technologies that have not been utilized by smallholder farmers (Chatterjee et al., 2015) as they fail to recognize the complex heterogeneity among farming populations (Emtage and Suh, 2005). Smallholder farming systems are heterogeneous because of differences in socio-economic and agro-ecological characteristics (Lesson et al., 1999; Mahapatra and Mitchell, 2011). It is important to consider the heterogeneity of the farmers so that any DST can be designed to reflect farmer needs and target appropriate end users. Farm typology analysis has been used to group farmers with similar circumstances based on selected criteria and has been especially helpful in targeting interventions for rapid transfer and adoption of appropriate technology (Alvarez and Nuthall, 2006). Many studies have addressed the importance of farm household typology influencing farm technology adoption (Bidogeza et al., 2009), nutrient management technologies (Chikowo et al., 2014; Daxini et al., 2019; Tittonell et al., 2006), resource use efficiency (Zingore et al., 2007), integrated pest management (Leeson et al., 1999), and climate smart agricultural practices (Lopez-Ridaura et al., 2018; Makate et al., 2018).

Farm typology studies are useful for understanding factors explaining the adoption and/or rejection of new technologies (Kostrowicki, 1977). From a practical point of view, identifying the reasons for farmer adoption and/or rejection of new DSTs is important for the agricultural society, policy makers and related economic sectors. In particular, the typology of farmers, along with their opinions on DSTs, can provide useful policy insights on whether and how these tools can contribute to diffusion of innovations and rural development.

Another challenge associated with DSTs is the limited on-going funding to maintain and update the tools (Gallardo et al., 2020). Incorporating useful information and decision support functions to social media platforms could have a more useful and sustainable impact (Thar et al., 2020). Rose et al. (2021) highlighted the need to incorporate social sustainability into technological trajectories by outlining a framework of multi-actor co-innovation to guide responsible socio-technical transitions.

2.7 Research Gaps

The following research gaps were identified based on this review of the literature:

1. There have been conflicting reports of fertilizer use in Myanmar, so that the Myanmar fertilizer use statistics may be considered unreliable (IFDC, 2018). Hence, there are concerns over the national data quality with very limited representative survey data on the actual farmers practices of fertilizer use in Myanmar (Haggblade et al., 2013; Weil, 2017). Despite this, farmers in Myanmar have consistently been encouraged to apply high levels of fertilizer (LIFT, 2016; Naing et al., 2008; Oo and Ekasingh, 2010; Tun et al., 2015) and many fertilizer response trials continue to be conducted in Myanmar (Weil, 2017). It is important to understand farmer perceptions towards fertilizer to better understand their utilization, management and actual decision making for designing and implementing successful interventions. Such understanding will help inform strategies aimed to enhance productivity and profitability of smallholders in Myanmar.

2. Mobile-based DSTs may offer opportunities to Myanmar farmers by providing them site-specific information to make better informed decisions. However, there is very limited literature regarding farmers use of ICTs in Myanmar and no study has considered factors related to the use and adoption of agricultural mobile apps in the Myanmar agricultural sector.

3. The low uptake of fertilizer DSTs by users from previous reports suggest that a better framework is needed and that the tools do not account for complex and heterogeneous

smallholder farming systems. This may be achieved by a typology analysis to target groups of farmers with similar circumstances follow by a participatory research with farmer groups with similar socio-economic characteristics so that the DSTs are designed to reflect the needs of targeted end users' groups.

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CHAPTER 3
Research Methods

This chapter provides a brief description of the study area, the process of the household survey and the FGD. The process of the household survey includes the sampling procedures such as village selection, sample size determination and farmer/household selection. The use of a mobile data collection tool, CommCare® is also described in detail with in-field experiences in the design and implementation of this digital data collection tool to capture data in complex farming systems in central Myanmar. The protocol of conducting the FGD with different farm types is also described.

3.1 Description of the study area

The study was carried out in three townships associated with the project fertilizer yield response trials. Fertilizer yield response trials for the ACIAR project have been established in three regions: Tatkon township (1 site), Zeyarthiri township (2 sties) and Taungoo township (1 site). Tatkon and Zeyarthiri townships are in the Nay Pyi Taw district and Taungoo township is in the upper region of the Bago district (Figure 5).

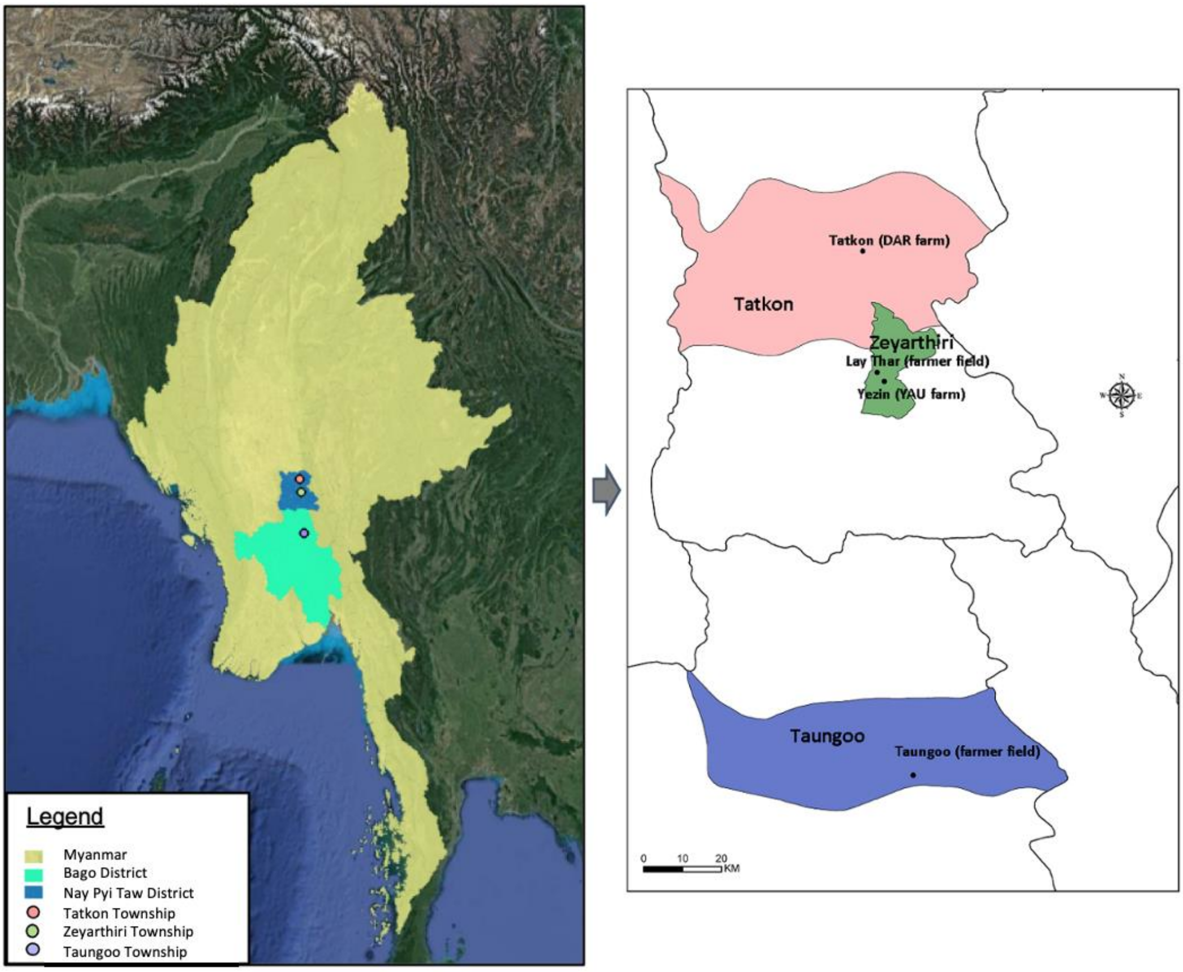


Figure 5. Map of Myanmar showing the districts; townships; trial sites and the study area

Tatkon township is located in the State of Nay Pyi Taw at 96° 30′ East and 20° 20′ North with an average altitude of 139.60 m above sea level. The total area is about 1802.35 square km (695.89 square miles) comprising 55 village tracts and 176 villages. The total population is about 220,600 (Myanmar Department of Settlement and Land Records, 2018).

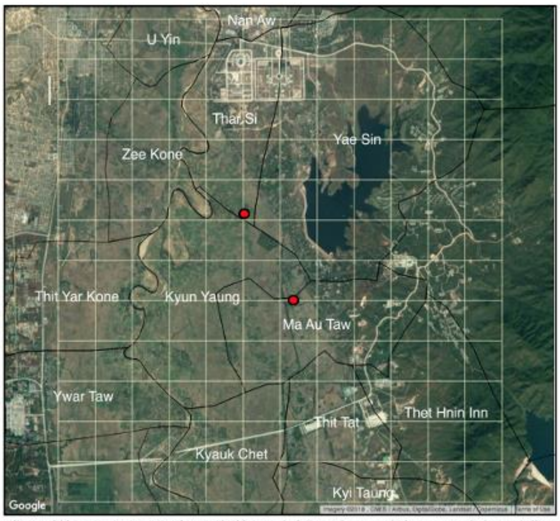
Zeyarthiri township is bordered by Pin Laung township to the east and Tatkon township and Pyinmana township to the north and south respectively. It lies between 19° 24′ and 20° 18′ North and 95° 40′ and 96° 40′ East and covers an area of 597.64 square km (230.75 square miles). It is one of the new townships established with the relocation of the administrative capital from Yangon to Nay Pyi Taw in November 2005 (Preecharushh, 2009). Zeyarthiri township is made up of 13 village tracts and 65 villages, with a population of 97,932 (Myanmar Department of Settlement and Land Records, 2018).

Taungoo township is located between 18° 56′ and 18°57′ North and 96° 25′ and 96° 27′ East with a total area of 1717.55 square km (663.15 square miles). It consists of 38 village tracts and 251 villages with a population of around 240,887 (Myanmar Department of Settlement and Land Records, 2018).

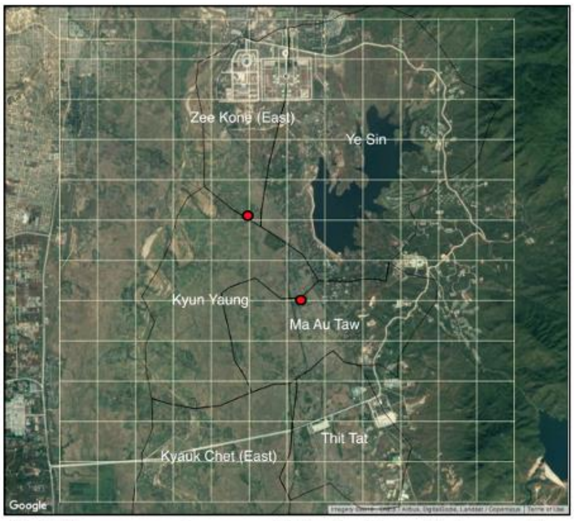
3.2 Sampling procedure

3.2.1 Village selection

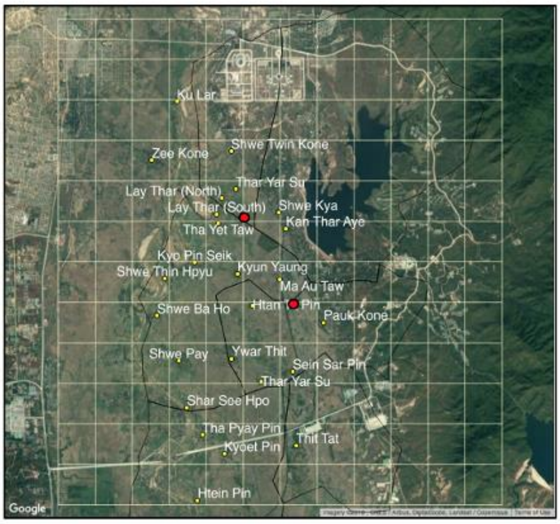
A multi-stage sampling technique (Sukhatme et al., 1984) was used to select the sample and the respondent smallholders. Tatkon, Zeyarthiri and Taungoo Townships were selected purposively since the ACIAR project trial sites were established within the townships. In the first stage, grids of 1000m x 1000m were overlaid for each trial site (Figure 6(i)). The purpose of the grid was to identify villages that would provide representative contextual settings from which to access farmer opinions and practices about fertilizer use. Then, within the grids, we identified the village tracts, which are combinations of villages (Figure 6ii)). Next, the villages included in the selected village tracts were identified (Figure 6(iii)). Ten villages were selected from each Township, providing 30 villages in total (Figure 6 (iv))). The villages were selected based on the number of farmers and the distance to the trial sites. The step-by-step village selection process for Zeyarthiri township is described in Figure 6 and the same steps were followed for Tatkon and Taungoo townships.



(i) Village tracts that falls within the grid were identified. The red dots represent the fertilizer yield response trials locations.



(ii) Village tracts that are within the Zeyarthiri township were selected.



(iii) Villages within the selected village tracts were identified. (Total of 31 villages)

(iv) Ten villages with the highest numbers of farmers were selected for the survey.

Figure 6. Step by step process of the village selection process for Zeyarthiri township

The layer of the maps of the village tract boundaries and the GIS locations of the villages were obtained from the Myanmar Information Management Unit (MIMU) and the farmer population data of the respective villages was obtained from the Department of Agriculture (DoA) Myanmar. The sampling procedure and village selection flow chat is presented in Figure 7.

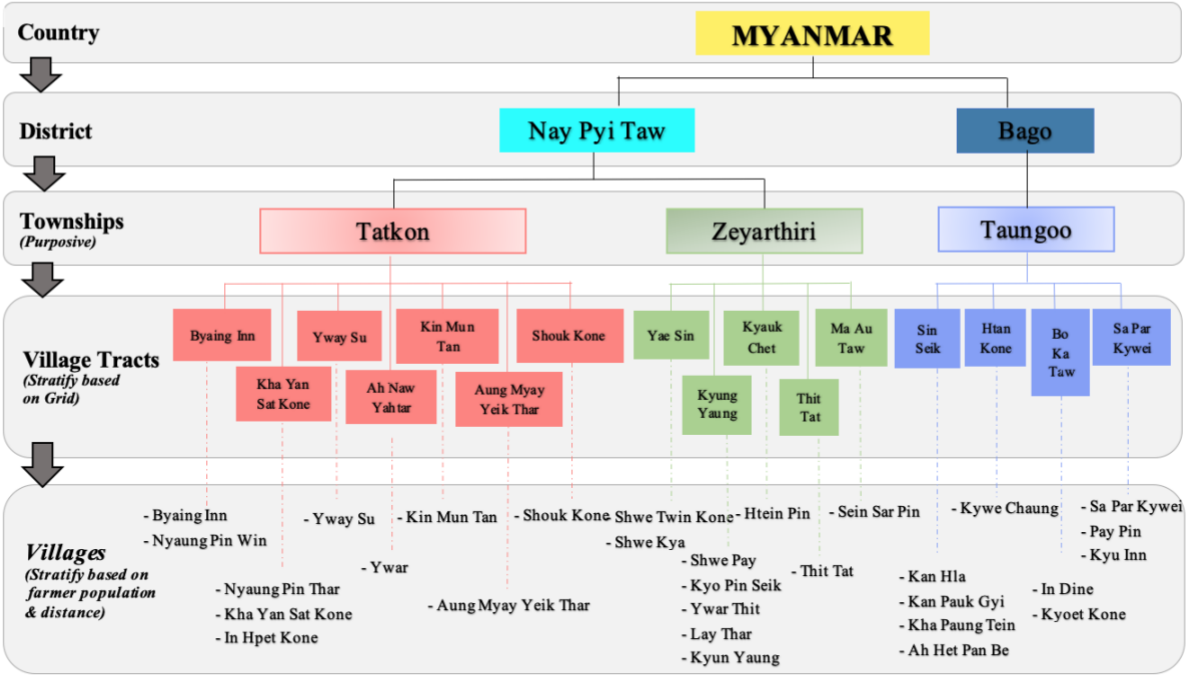


Figure 7. Sampling procedures and village selection flowchart

3.2.2 Sample size determination

The total number of farmers within the grid for each Township were identified with the help of the local DoA extension officers. To generate a representative sample of the farmer populations in each township, a 20:1 sample-to-item ratio (Costello and Osborne, 2005) was used. The questionnaire contained 30 items/topics; hence, 600 respondents were randomly selected for the study (Memon et al., 2020). To have respondents from each township equally, 6% of the farmers from each township were specified, comprising 258 respondents in Tatkon, 196 respondents in Zeyarthiri and 146 respondents in Taungoo (Table 7). A ratio of 8:2 for male and female farmers was selected based on the gender ratio within the population in the study area.

Table 7. Sample size determination

	Tatkon	*Zeyarthiri*		*Taungoo*	*Total*
Township populations of farmers	14,879	7,399		12,536	34,814
		Male 5,832	Female 1,562		
Total farmers within the grid	4,300	3,261		2,388	9,949
Sample Size	258	196		146	600
Male sample size	208	149		112	469
Female sample size	50	47		34	131

3.2.3 Farmer/household selection

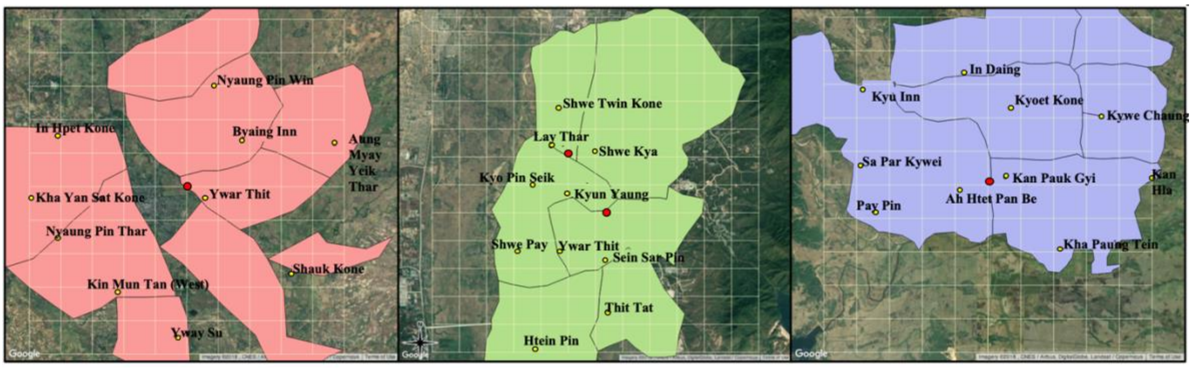
Village farmer population lists were obtained from each Village Leader, who was consulted prior to the survey interviews. A stratified systematic sampling technique (Levy and Lemeshow, 2013) was used to randomly select the sample farmers. Farmer population were stratified by crop type and gender. Farmers cultivating the focus cereal crops (rice, maize) were selected. The first farmer to be interviewed was randomly selected to reduce the bias of household selection. If the farmer was not available at the time of the interview, or declined to participate, the next farmer on the list was selected. The selected farmers were contacted a day in advance and notified of the estimated time and place of the interview, which was either at the chief farmer's house or at Knowledge Transfer Centers. The criteria for respondent farmers included farmers who:

- Were the head of the household or household member who led the farm work
- Were actively cultivating land either as a landowner or land tenant, and
- Expressed availability and willingness to participate in the survey.

3.3 Field data collection

3.3.1 Survey

A household survey was conducted from May to July 2018 in the selected 30 villages (Figure 8). The objective of the survey was to understand farmers' fertilizer management and how they make decisions regarding fertilizer use, and their perceptions of agricultural mobile apps in aiding farm decision making and information sharing. The survey was conducted using CommCare®, a mobile application for data collection (Dimagi 2017; Ziegler 2017). Four agricultural graduates from Yezin Agricultural University (YAU) were hired as survey enumerators. They were trained and given access to the questionnaire for data collection. Survey enumerators logged into CommCare® on their phone or tablet to gain access to the questionnaire.



a) Tatkon township b) Zeyarthiri township c) Taungoo township

Figure 8. Village tract boundaries and selected villages for the survey

3.3.2 CommCare®

CommCare® is a customizable, open-source mobile platform that enables nonprogrammers to build mobile applications for data collection. It operates on Android and Java-enabled phones and has multiple languages. CommCare® enhances data collection by directly digitizing the information collected. It has been used widely to assist data collection across health, agriculture, and development sectors in low-resource settings. It has been actively used in over 300 projects in more than 50 countries (Flaming et al., 2016). CommCare® is free for basic features mainly for individual researchers, small projects, and small numbers of mobile users (up to 10), but requires an annual subscription for a fuller range of features for a larger number of mobile users and support. Monthly and annual subscription fees vary from US$2,000 up to US$12,000 depending on the plan. The use of CommCare® enhances data collection compared with traditional paper-based approaches (which require manual entry of results into a computer database) because it directly digitizes the information collected.

In a healthcare study, Medhi et al. (2012) found that data completeness was improved from 67% to 84%, reducing the average data transmission time from 45 days to 8 hours by using CommCare®. Flaming et al. (2016) explored the impact of CommCare® on frontline programs in the health sector and provided strong evidence that the performance of frontline workers strengthened and improved the outcomes and behaviors of clients. CommCare® has also been used by projects in the agriculture sector to assist with data collection, monitor training sessions and also keep track of farmers' activities (Dimagi, 2017; Ziegler, 2017). A review of all the published and unpublished studies about the CommCare platform suggested that CommCare® is one of the most widely used advanced platforms for frontline workers (Chatfield et al., 2013).

The process of data collection using CommCare® is illustrated in
Figure 9.

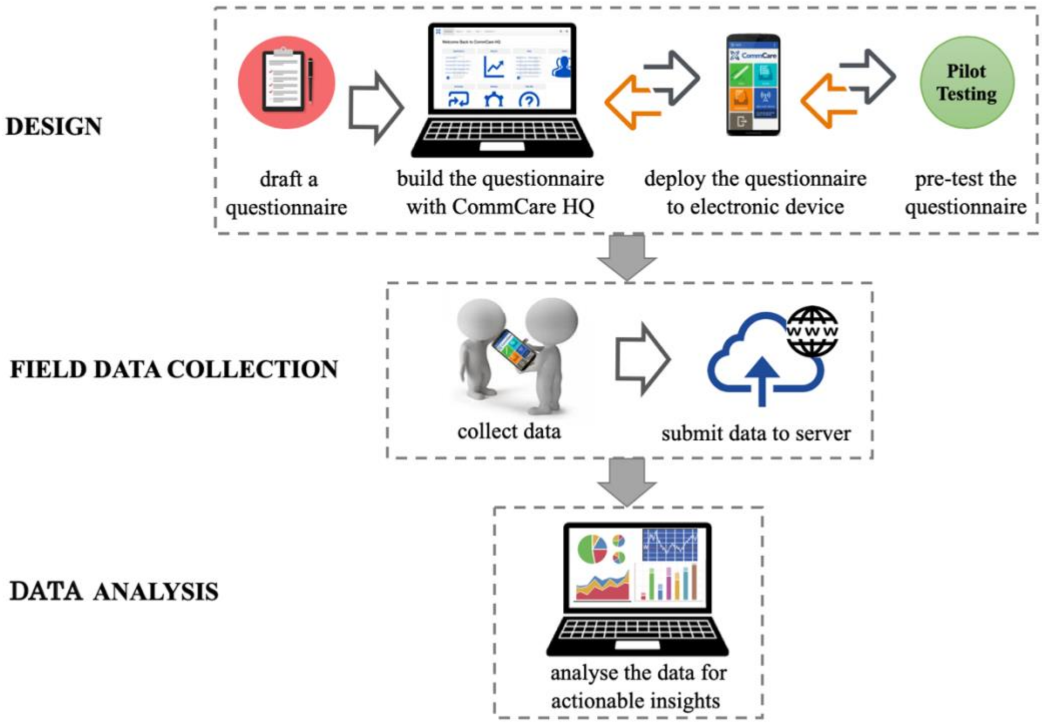


Figure 9. Overview of the digital collection process with CommCare®

In the designing stage, a questionnaire was built in the CommCare HQ (www.CommCarehq.org), a website used for application design and management as well as accessing data and managing mobile workers. The preparation, setting up and building of questionnaire requires time investment, especially when implementing for the first time. Multiple pilot testing of the app and questionnaire were conducted prior to the actual survey. The questionnaire can be reused for follow up or future similar surveys or modified for different farming systems. To avoid data loss the forms always need to be submitted once there is a network available.

The field data collection stage follows after the questionnaire has been implemented in the CommCare HQ and deployed to mobile phones or tablets. Survey enumerators can log into CommCare® application on their phones or tablets to gain access to the questionnaire. They then fill out the questionnaire and submit directly to the server or save it to be submitted later. After the questionnaires have been uploaded to the server, the data can be extracted and analyzed in real time. Real-time data analysis can detect data inconsistencies and locate errors which improve the data quality (Schuster and Brito, 2011). The data can be reviewed at the end of each survey day and any errors detected can be easily amended.

3.3.3 Survey Questionnaire

The survey questionnaire included questions about socio-economic characteristics of the household, farm size, information on crops grown, inputs used and crop yields for different crops, and prices received and paid by smallholders. Also included were questions specific to each farmer about fertilizer management and practices as well as information of farmers' access to mobile phones (smartphones), agricultural mobile apps, utilization, and challenges.

The questionnaire form was initially drafted on paper and built in CommCare HQ. The CommCare® form function consisted of text, checkboxes for multiple-choice questions, number entry questions, image capture, hidden values (a special question type hidden from mobile users to perform calculation), labels and recording of GPS coordinates. The "repeat group" function was used to repeat a set of questions for different types of crops. The set of questions was information on cultivation practices, labor, inputs used, yield and marketing. A question asking the number of crops grown is required prior to setting up the repeat group. Based on the number of crops grown by the respondent farmers, a set of questions was used to repeat for each crop. For questions that would only make sense within the context of a previous answer, skip logic was used. The skip logic avoided non-relevant questions. This enabled collection of clear and consistent data avoiding participant fatigue and annoyance while minimizing the collection time.

GPS coordinates were also recorded to obtain measurement of the distance from individual farmer fields to the nearest market. The automatic GPS capture feature of CommCare® allowed capture of a GPS location with no intervention from the mobile user. The GPS coordinates enhanced the value of data by enabling more sophisticated geo-spatial analysis such as network analysis, integration with soil and topographic maps, and visualization on Google Earth.

A pilot survey (Lancaster et al. 2004) was conducted to test the flow and format of the questionnaire and further revised. The draft questionnaire was pre-tested with 10 non-sampled farmers. The final survey questionnaire is provided as Appendix I. The length of the questionnaire varied mainly with the number of crops cultivated by the individual farmers and the type of fertilizers used.

3.3.4 Advantages and Disadvantages of using CommCare®

There are many advantages and some disadvantages in using CommCare® (Table 8). The feedback mechanism in CommCare® offers knowledge-sharing opportunity and gives feedback to the respondent during the survey. Hidden value calculations can be inserted to provide farmers with estimates of their total cost of production and seasonal profit. This is a very useful feature that can translate data into meaningful advice for individual farmers. Other agricultural research projects adopting CommCare® for data collection have reported that giving rapid feedback and sharing information allows better interaction with farmers and improves relationships (Roxburgh et al., 2016).

Table 8. Advantages and disadvantages of using CommCare®

	Advantages	Disadvantages
Time	- comparatively shorter time in field - reduces time for training enumerators as there is no need to cover the coding responses - saves significant time for data entry - reduces time lag between data collection and analysis	- requires more time investment while building the app compared to paper-based
Cost	- no cost of printing - Android tablets are versatile and could be borrowed from existing users. - dedicated devices could be used for multiple surveys to minimize cost	- requires an additional phone or tablet - increase in implementation costs to purchase quality and reliable Android tablets
Storage	- saves storage space as it does not require bulky paper-based questionnaires	- data can be lost with software malfunction - requires a backup storage
Logistics	- easy to carry and transport	- need to be careful of accidental damage, theft, and weather conditions
Visualization	- able to see the questionnaire in the dark, especially useful in remote villages with no electricity	- requires a power bank or spare battery - screens can become unresponsive with rain or extreme heat
Accessibility	- can be used offline - can also be reviewed on site in real time	- data can be lost if there is no synchronization with the server

Data Quality	- improved rigor and accuracy of data - minimizes data entry errors - prevents missing data - able to valid and modified data - eliminates coding - filters, controls, skip logics contribute to more effective and accurate data gathering - reduces the risk of human errors	- requires setting up formulas and creating calculations in building the app

Moreover, hidden value calculations can also be used to validate the answers with respondents. For example, in a series of questions asking how much land a farmer owns, hidden value can be used to add them up; if the farmer owns 4 ha and rents out 2 ha and rents in 1 ha, the hidden value calculates that the farmer is currently farming 3 ha.

3.3.5 Recommendations based on lessons learnt from field experience

From the field experience, the following recommendations are based on CommCare® process flow graph (
Figure 9).

Design: Before building the questionnaire in the CommCare HQ, it is wise to prepare a draft on paper and pilot it with a few farmers and local extension officer to obtain multiple choice answers. Providing multiple-choice and check-box questions save time for data cleaning with respect to spelling and different terminologies used. Include "others" for any choice/answers not given and then follow with an 'other detail' text question with skip logic to include further detail. When asking number-entry questions, be specific whether the answer should be integer or decimal. Grouping the questions with the same focus is a good way to organize the questions in CommCare®.

It is helpful to create tick boxes in CommCare® ensure that vital questions are answered. By displaying hint messages, further instructions can be provided. Also, by inserting formulae and calculations into apps allows validation of responses. Comments can be added after images captured at the end of the questionnaire. Such comments can be useful for qualitative observations. It is better to add GIS data capturing at the tail end of the questionnaire to minimize bandwidth-related problems. If the information on multiple crops/animals is to be collected, the repeat group option is valuable.

However, using a repeat group creates a separate excel sheet. If multiple units are available, provide a separate multiple-choice question to enable selection of the appropriate unit. Pre-test the flow of the questionnaire multiple times to check the app is easy to navigate and has a user-friendly interface. Write notes of the changes when making a new version to be deployed. If required, the CommCare® platform can obtain respondent consent prior to the survey proceeding.

Field data collection: Data collection in the field is a difficult task. Some precautions include having a spare mobile or tablet with the CommCare® app installed and the questionnaire uploaded in case of any unexpected events. It is also necessary to check whether the CommCare® app in the mobile is up-to-date and is compatible with the CommCare HQ version. When interviewing in the field with a digital device, it is important to have a backup power bank battery charger. Data review at the end of each survey day is recommended to detect any missing questions and to identify any inconsistencies in the data. If necessary, questionnaire refinement and noting of changes can be made for the enumerators. When using groups of enumerators to collect data, using internet messaging groups like WhatsApp can assist with rapid issue resolution and better communication. An additional advantage in field data collection is to use enumerators with general knowledge of the topic to be interviewed and prior field survey experience.

Data Analysis: High-quality data collection and smooth data analysis are heavily dependent on app building and questionnaire development at the design stage. Once data have been collected and sent to the server, it can easily be exported to a file (Excel, CSV, JSON, etc.). However, if the questionnaire has not been set up correctly, the data exported from CommCare® can pose problems for further processing using modern data science tools such as Tidyyerse in the R programming environment (Wickham, 2017).

3.4 Data analysis

The data analysis used to address individual research questions is described in detail in each chapter.

3.4.1 Probit analysis

Probit analysis (Greene, 2003) was employed to answer research question 2 in evaluating the socio-economic factors influencing the use of agricultural apps mobile apps and it is described in detail in Chapter 6.

3.4.2 Typology analysis

Typology Analysis (Gorton et al., 2008; Kobrich et al., 2003) was used to address research question 3 to create different farm household types based on socio-economic characteristics which underlie the adoption of mobile based fertilizer DSTs. The data analysis is described fully in Chapter 7.

3.5 Focus group discussions

The focus group method (Krueger, 1988) was used to collect qualitative data. FGDs are designed to obtain participants perceptions on a well-defined area of interest and are found to be a valuable way to obtain a range of perceptions, feelings and opinions from interviewing groups of people (Yin, 2015). The objective of the FGDs was to introduce the concept of a mobile-based DST to Myanmar farmers and find out how they felt about using such tools in making their fertilizer decisions. In FGDs, opinions of individual participants are converted to a more or less shared group opinion (Kraaijvanger et al., 2016).

In this study, FGD workshops were conducted by personal interview with six different groups, one for each of the farmer groups derived from the typology analysis (see Chapter 8). This is valuable because the groups of farmers with similar farm types face similar constraints and may generate similar management strategies. But individual farmer characteristics, decisions, values, culture, background or personal goals will remain different and the study can account for the observed individual differences (Alvarez, 2018). This approach enabled investigation of more diverse views and allowed comparison of results between groups.

Altogether there were 34 participants in six different farm types. The number of participants in each group varied from four to eight. The list of farmers in each group was obtained from the household survey. Farmers from each group were randomly selected and invited to the group discussions with the help of the agricultural extension officers. Farmers were given sticky notes on which to write their answers. Farmers who needed assistance with writing were helped. Most farmers were able to write. In the discussion we evaluated the need for a fertilizer DST by smallholder farmers in Myanmar and identified whether a discussion format would be more useful. With these objectives, discussions were planned based on the 3 main topics:

- Typology Validation
- Fertilizer Decisions/ Risks and
- Decision Support Tools/Apps.

The protocol for the FGD is provided in the Appendix II. Focus group responses were translated from Burmese to English and analyzed in NVivo Qualitative data analysis software (version 12.3.0) (Bazeley and Jackson, 2013).

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CHAPTER 4
Survey Results

In this chapter the general results from the household survey are described. This includes the socio-economic characteristics of farmers including age, farming age and experience, marital status, education, household size, off-farm activities, land and livestock ownership as well as soil types and the type of crops cultivated in the study area.

4.1 Demographic characteristics of surveyed farmers

4.1.1 Age

The overall mean age of the farmers interviewed was 50 years with a slightly higher average age for Zeyarthiri township (about 52 years) compared to Tatkon township (48 years) and Taungoo (49 years). The age data categorized by age group indicated that there was a higher population of farmers over 50 years in the survey area with 48% of the male farmers and 47% of the female farmers and a lower population of young farmers under the age of 35 (15% male and 12% female). The majority of the farmers in the survey were in the age interval 36-50 years (37% male and 41% female). Figure 10 shows the age distribution of the surveyed farmers according to gender and township.

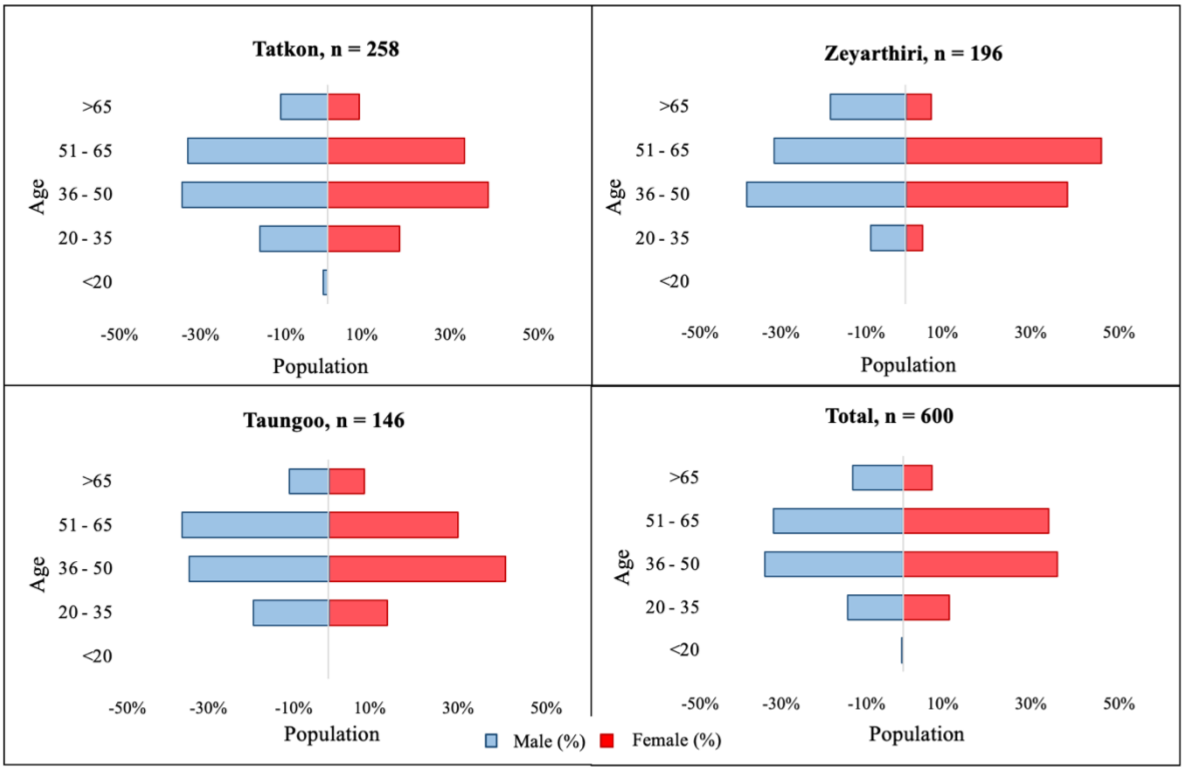

Figure 10. Population pyramids of the surveyed farmers

4.1.2. Farming age

The youngest age to begin farming in the study areas was 15 years old and farmers continue to farm up to over 70 years. Farmers who began farming at a young age were commonly men, while most farmers who began farming at an older age, over 60 years, were mostly women, where they have taken over the role of farming later in their life. The average age to begin farming was higher by 2 years in Zeyarthiri township, 24 years compared to Tatkon and Taungoo townships.

4.1.3 Farming experience

The farming experience of the surveyed farmers varied from a minimum of 1 year to a maximum of 65 years with an average farming experience of 27 years. The distribution of farmers by farming experience in the study area is provided in Table 9. The majority of the farmers indicated that they have 21 – 30 years of farming experience and the minority having over 50 years of experience in all three townships. Male farmers have an average farming experience of 28 years while female farmers have 25 years.

Table 9. Distribution of farmers by years of farming

Farming Years	Tatkon		Zeyarthiri		Taungoo		Total	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
1 - 10	38	15	16	8	17	12	71	12
11 - 20	59	23	47	24	31	21	137	23
21 - 30	69	27	61	31	44	30	174	29
31 - 40	55	21	40	20	33	23	128	21
41 - 50	31	12	25	13	14	10	70	12
Above 50	6	2	7	4	7	5	20	3
Total	258	100	196	100	146	100	600	100

4.1.4 Marital status

Regarding marital status, 6%, 85%, 1% and 8% were single, married, divorced/separated and widowed/er, respectively. This shows that marriage is common for rural household heads and the divorce rate is very low. There was a higher population of single male farmers (26%) compared to female farmers (12%) and a higher population of female widower (28%) compared to male (21%). This reflects the higher mortality rate of men and suggests that women are less likely to remarry.

4.1.5 Educational attainment and literacy

Figure 11 contains information about the educational status of surveyed farmers. Most of the farmers had primary school education with 49% in Tatkon, 47% in Zeyarthiri and 74% in Taungoo townships. Farmers with high school education was found to be higher in Tatkon (12%) and Zeyarthiri (11%) compared to only 8% in Taungoo. Farmers with tertiary education were found in all three of the townships while farmers who have graduated with a degree is only found in Zeyarthiri Township.

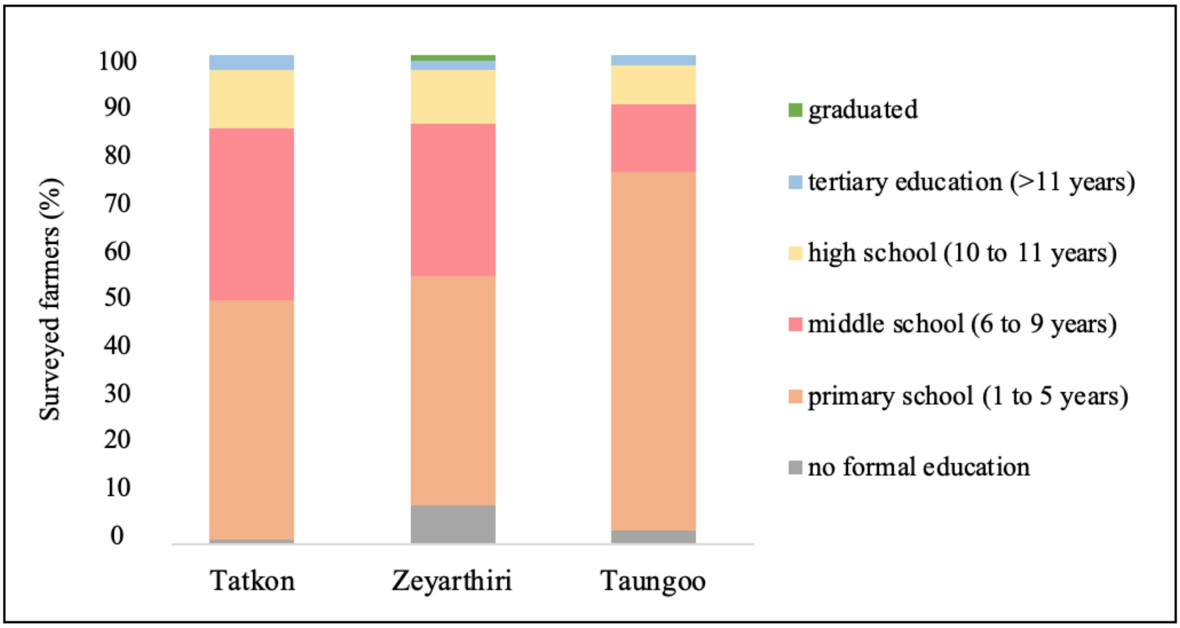

Figure 11. Educational attainment of the surveyed farmers by township

With respect to gender, there was a higher population of female farmers without any form of formal education (14%) as compared to male farmers (1%) suggesting a higher literacy rates in male (Figure 12). Female education can have a significant influence on improving decision making and technical efficiencies (Rahman, 2010).

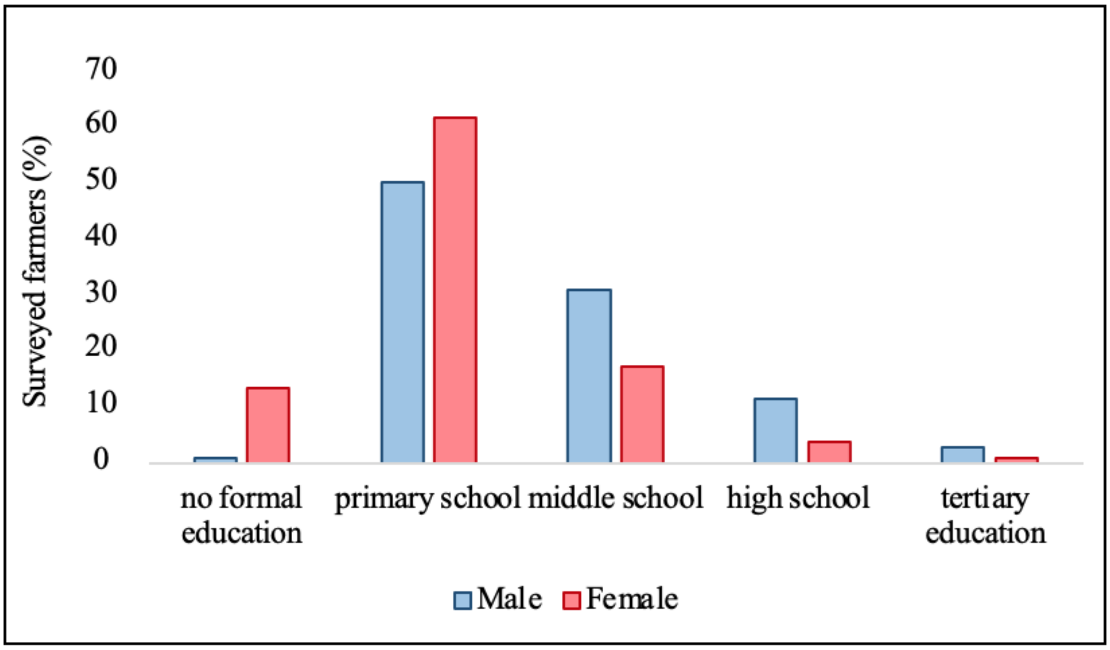

Figure 12. Educational attainment of the surveyed farmers by gender

4.1.6 Household size

From the survey, the average household size was 4.8 which remains consistent across the three townships with 4.8 family members in Tatkon and Zeyarthiri and 4.7 in Taungoo.

4.1.7 Off-farm activities

The labor used in agriculture in Myanmar is one of the highest in Southeast Asia accounting for over 50% of the workforce (Cunningham and Munoz, 2017). This is more obvious in the rural areas where two thirds of the total jobs are directly or indirectly linked to the agriculture sector with half of rural workers are women (WorldBank, 2015). Average, per capita income from agriculture averages around USD200 per year per crop (Raitzer et al., 2015), which is not sufficient to sustain the household. Hence off-farm work helps to generate more household income. According to the survey, 38% of the sample had family members participating in off-farm activities in Tatkon township and 66% and 36% in Zeyarthiri and Taungoo townships, respectively. This suggests a higher opportunity for off-farm activities in Zeyarthiri township considering the recent urbanization and transformation of the country's Capital City. Table 10 shows the percentage of farm household members involved in off -farm activities and the monthly average income based on the activity and township.

Table 10. Monthly average income (AUD) of non-farm activities based on townships

Off-farm activity	**Tatkon**		**Zeyarthiri**		**Taungoo**	
	%	Income	%	Income	%	Income
Casual wage earner	6	$113	10	$101	6	$125
Migrate to other countries	22	$321	5	$128	12	$331
Salary earner from private firm	22	$220	30	$179	24	$178
Salary earner from public firm	22	$172	24	$186	12	$189
Shop owner	12	$182	19	$132	23	$173
Trader	2	$460			6	$350
Transport business	7	$230	12	$340	3	$425
Tailor	5	$124			11	$89
Carpenter	1	$100			3	$178
Vet	1	$80				

4.1.8 Livestock ownership

Another form of farm activity to generate income was livestock raising. Livestock is a relatively small sector, and contributes only to about 7.5 percent of the agriculture GDP (WorldBank, 2017). Ninety percent of the farmers in Taungoo township raise one or more type of livestock, followed by 77% in Zeyarthiri and 59% in Tatkon township. A higher percentage of farmers in Taungoo raised buffalo, cattle and chicken compared to the Tatkon and Zeyarthiri (Table 11). A higher population of pigs were raised in Zeyarthiri. The surveyed farmers mentioned that the primary reason for livestock raising was for income and source of food in all three townships. Raising livestock as an investment to fund child education and for marriage, in some cases.

Table 11. Livestock ownership per township

Livestock	**Tatkon**		**Zeyarthiri**		**Taungoo**	
	No.	**%**	**No.**	**%**	**No.**	**%**
Buffalo	32	12	4	2	38	26
Cattle	105	41	72	37	77	53
Chicken	115	45	96	49	93	64
Duck	8	3	4	2	6	4
Pig	84	33	81	41	52	36

4.1.9 Farming asset ownership

The agricultural mechanization in Myanmar remains low. Majority of the farmers owned sprayers in all three townships and 25% had tractors with a higher number of tractor ownership in Taungoo (34%) (Table 12).

Table 12. Ownership of farming tools per township

Farming Assets	**Tatkon**		**Zeyarthiri**		**Taungoo**	
	No.	**%**	**No.**	**%**	**No.**	**%**
Sprayer	243	94	177	90	103	71
Tractor	48	19	51	26	49	34
Thresher	16	6	20	10	15	10
Water Pump	167	65	76	39	48	33

Only a few farmers possessed threshers (98.5%). Water pumps for irrigation were owned by most farmers in Tatkon (65%), compared to 39% and 33% in Zeyarthiri and Taungoo respectively.

4.2 Land types in Myanmar

There are two major types of land in Myanmar commonly known as lowland (Le) and upland (Yar). Lowlands are fields which can retain water and are mostly paddy fields where rice production is possible, whereas uplands are dry fields and are allocated for other field crops such as maize and sugarcane, etc. (Hein et al., 2017). Figure 13 showed the different types of land of the surveyed farmers. The mean cultivated land area of lowland was higher than upland in all three townships, suggesting a larger area of lowland in the study area.

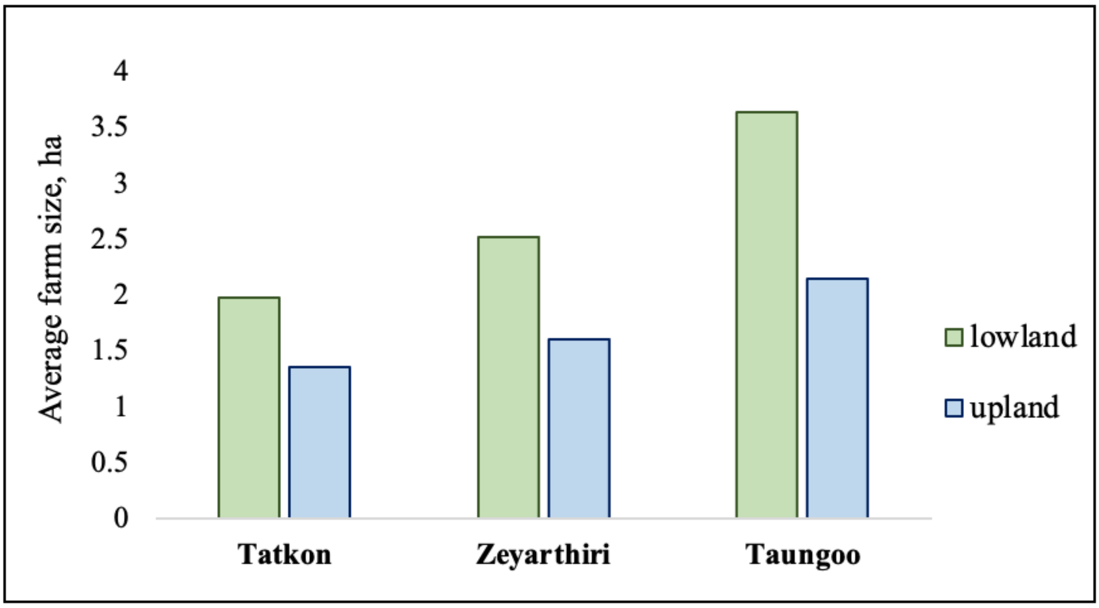

Figure 13. Average farm size of surveyed farmers by land type (lowland and upland)

4.2.1 Land ownership of farmers

Myanmar is abundance in land with 67.6 million hectares with an average land holding size of 2.7 ha, which is high compared to other Asian countries (Raitzer et al., 2015). The land ownership for farmers in the study areas varied between 0.1 and 19.1 ha. The average farm size remained consistent for Tatkon and Zeyarthiri with 2.5 ha and a higher average size in Taungoo with 4.3 ha. These average values were found to be slightly higher than the country average estimated at 2.21 ha from the 2014 Agriculture Census. Farm sizes of most farmers were 2 ha or less in Tatkon (65%) and Zeyarthiri (57%) while farm sizes ranged between 2.1 to 4 ha for most farmers in Taungoo (37%) (Table 13). The average farm size of male-headed households (3 ha) was only marginally larger than that of female-headed households (2.7 ha) (data not presented in table).

Table 13. Landownership by surveyed farmers

Farm Size (ha)	Tatkon		Zeyarthiri		Taungoo		Total	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Up to 1	57	30	50	26	7	5	115	19
1.1 to 2	90	35	60	31	27	18	177	30
2.1 to 3	37	14	37	19	23	16	97	16
3.1 to 4	37	14	21	11	31	21	89	15
4.1 to 5	7	3	8	4	10	7	25	4
5.1 to 7	21	8	10	5	22	15	53	9
7.1 to 10	6	2	7	4	17	12	30	5
Above 10	3	1	3	2	8	5	14	2
Total	258	100	196	100	146	100	600	100

4.2.2 Soil types in the study area

As expected, the soils varied from field to field. According to Hadden (2008), the townships in the central dry zone of Myanmar are characterized by clay, sandy loam and sandy soils that include gravel. Farmers from the survey were asked about the color and type of soil of their largest plot and the responses are shown in Figure 14 and Figure 15. Farmers were further asked whether they thought their soils were "good" or "bad". The responses are shown in Figure 16. Most of the farmers in all three -township considered that they have good soil conditions which were ideal for cultivation. In contrast, 10% of the farmers in Tatkon and Zeyarthiri and 25% of the farmers in Taungoo considered that they bad soils, being degraded soil or compact soils, which are not good for cultivation.

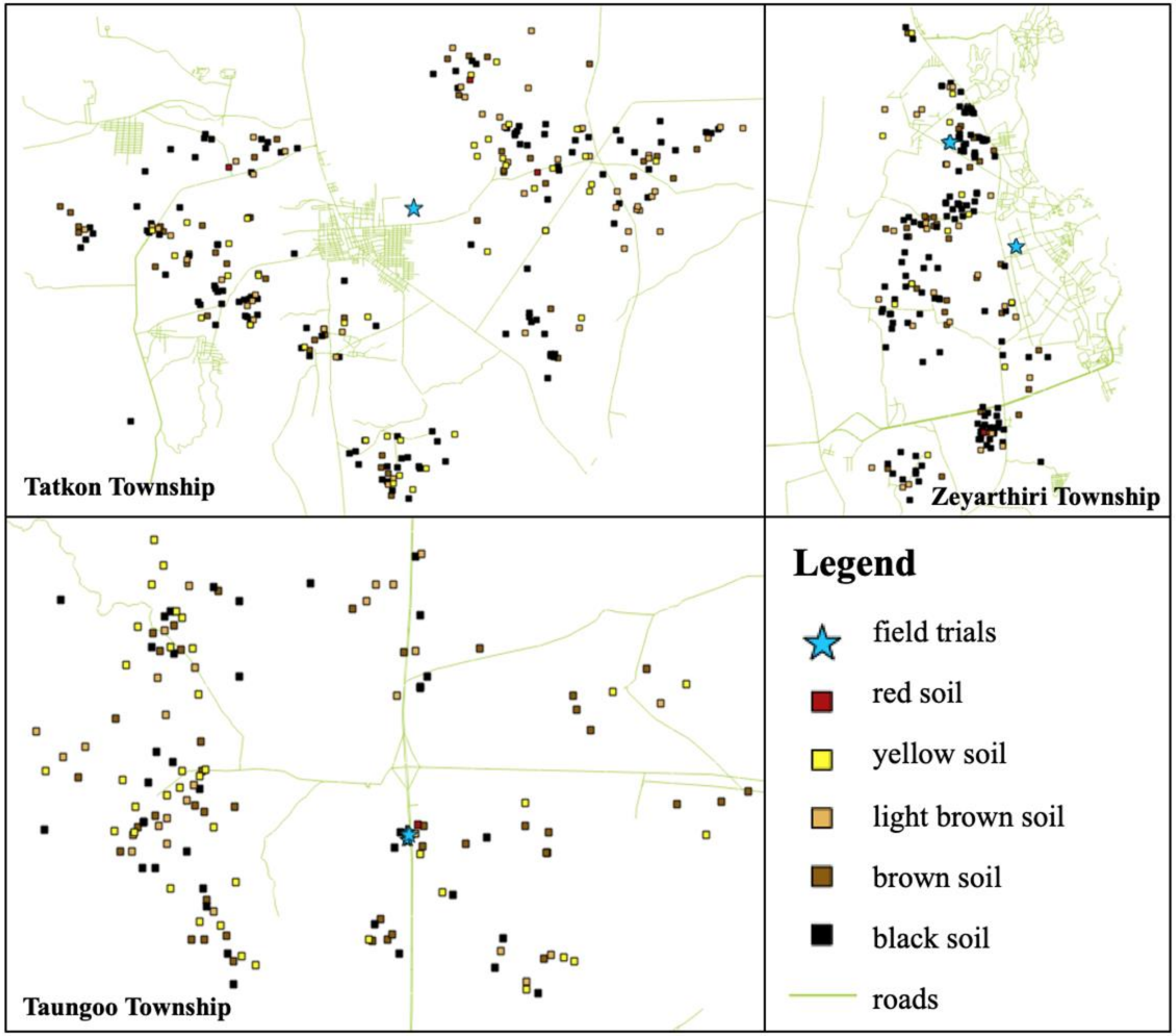

Figure 14. Soil color of surveyed farmers' largest field

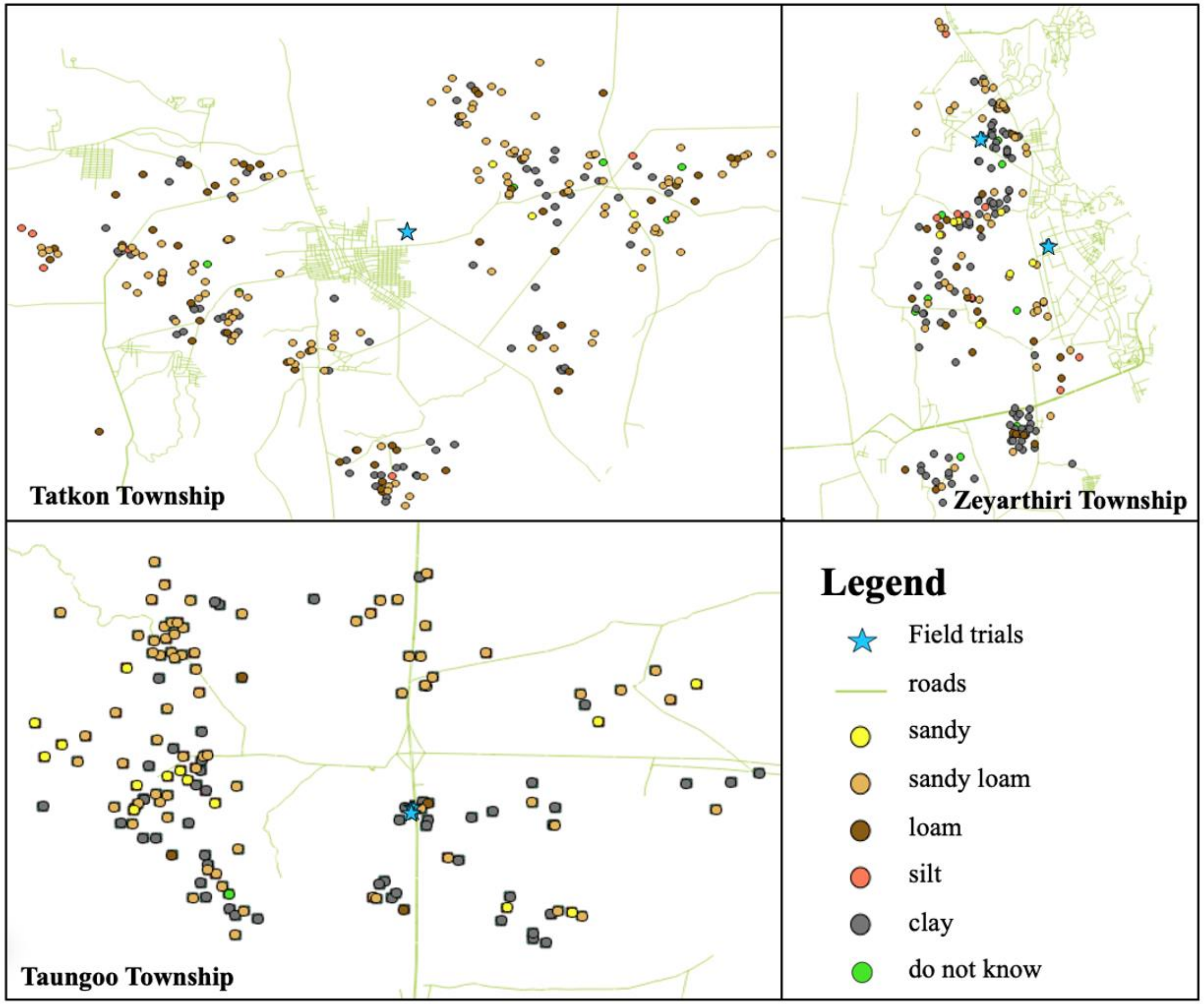

Figure 15. Soil type of surveyed farmers' largest field

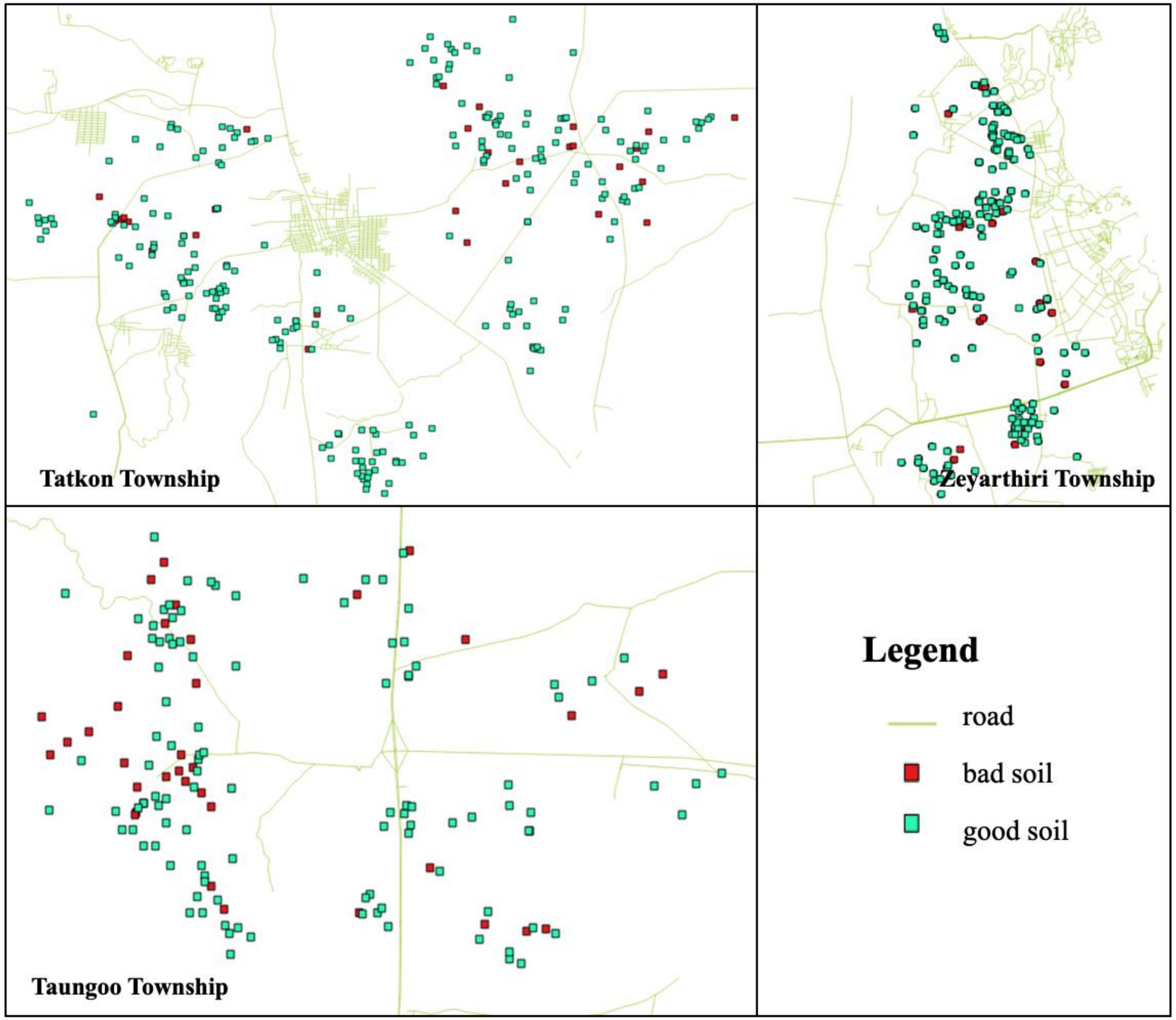

Figure 16. Status of soil (good/bad) of survey farmers' field

4.3 Crops

A large share of Myanmar's agriculture land is used for paddy rice cultivation, accounting for 70% of total arable land and constituting 30% of agricultural output and 95% of total cereal output (WorldBank, 2017). The country's rice self-sufficiency policy has led farmers to cultivate rice under in all irrigated areas (Cunningham and Munoz, 2017). This is consistent with the survey results where paddy was cultivated by a majority of the farmers in the study area (Figure 17). Other crops include maize, pulses (green gram, black gram, chickpea, lablab) and sesame which were grown either during the second season of the rice-based farming systems or on uplands. Crops such as sugarcane, onion, chilli, potato, watermelon and vegetables were also cultivated for cash and food in the study areas, although these crops have not been focused in this survey.

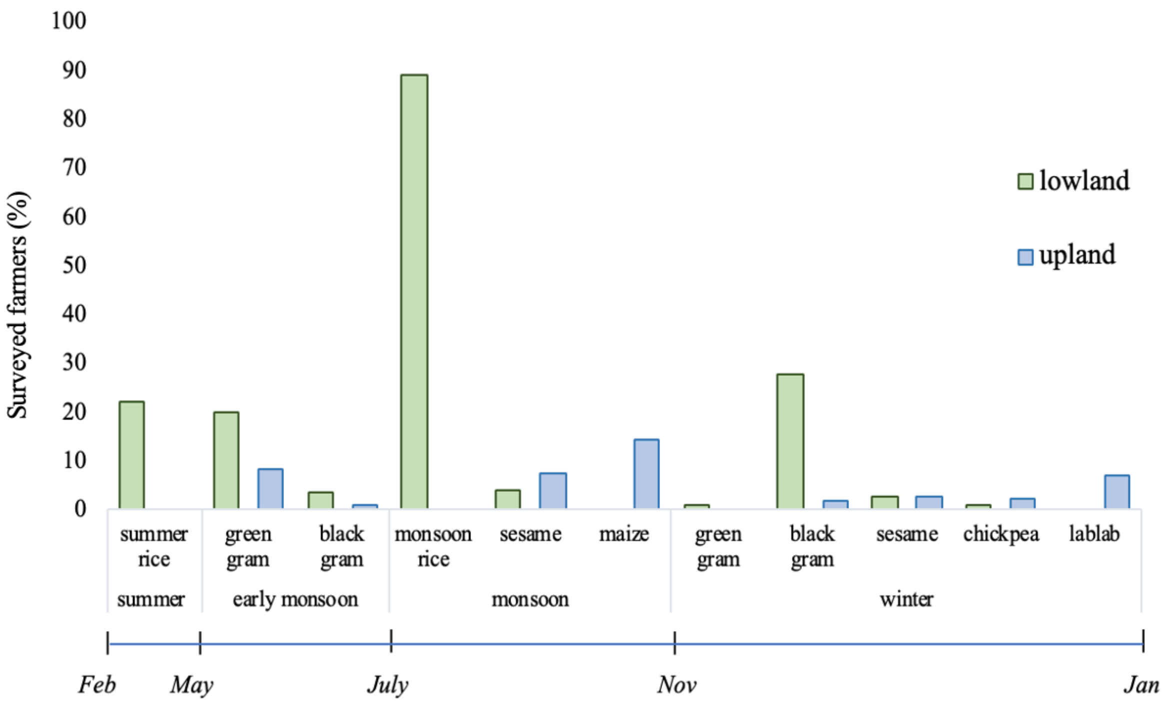

Figure 17. Different type of crops grown in lowland and upland in the study area

The cropping calendar based on the type of land in the study areas is provided in Figure 18.. Although monsoon rice was found to be cultivated by majority of the farmers in all three townships, there was a diversity of crops being grown. For upland, green gram, maize and sesame were found to be dominating crops in Tatkon while maize, lablab and sesame were found to be cultivated in Zeyarthiri and Taungoo townships.

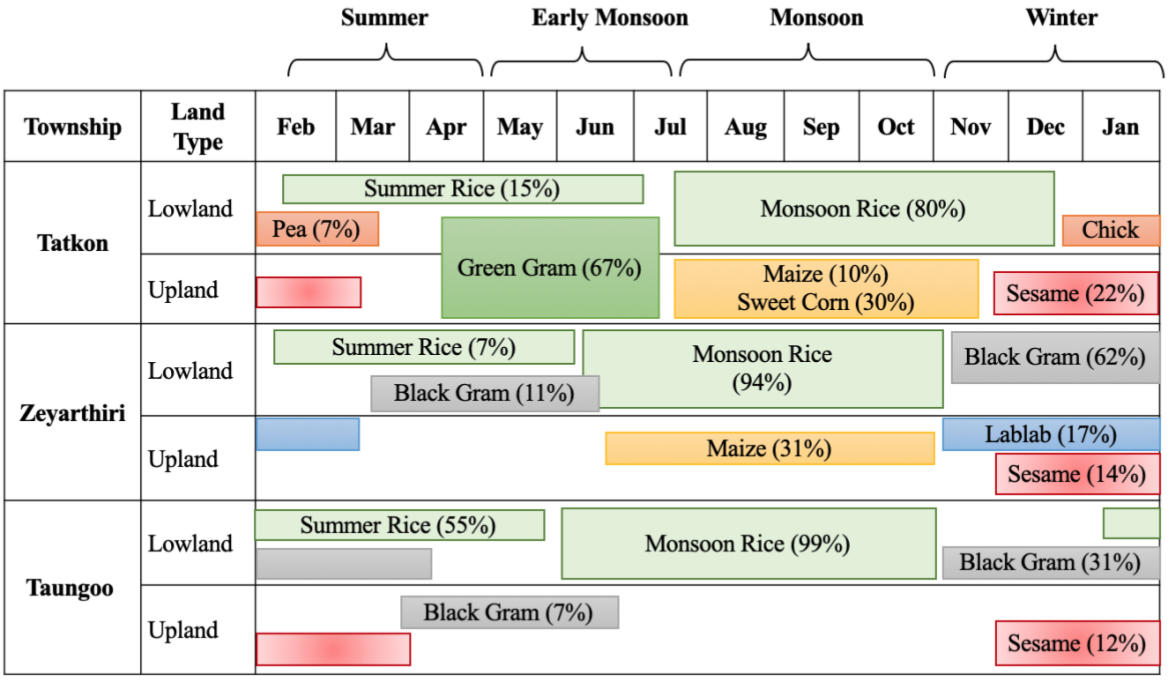

Figure 18. Cropping calendar of the surveyed farmers

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Chapter 5

Journal Paper 1

Recommended Vs Practice: Smallholder fertilizer decisions in central Myanmar

This chapter has been published as follows:

Thar, S.P., Farquharson, R. J., Ramilan, T., Coggins, S., and Chen, D. (2021). Recommended Vs Practice: Smallholder fertilizer decisions in central Myanmar. *Agriculture, 11*(1), 65. MDPI AG. Retrieved from http://dx.doi.org/10.3390/agriculture11010065.

Abstract

Agriculture in Myanmar has substantial development potential given the abundance of land, water, and labor resources in the country. Despite this, agricultural productivity in Myanmar is low and farm incomes are amongst the lowest in Asia. The underperformance of crops and low yield is widely reported to be due to low fertilizer use by smallholders. This study investigated the perceptions of smallholders about fertilizer use for cereal crops by considering their motives and decision making. We reported results of a 600 smallholders' survey and tested whether the reportedly low levels of fertilizer use by smallholders are generally true for central Myanmar. We compared the fertilizer application timing against recommended "good management practices". Among the surveyed rice farmers, the average fertilizer applied was much higher than previously reported national average fertilizer rates while the majority of the surveyed maize farmers were found to be applying less than the national recommended rates. With respect to timing, nearly half of the surveyed smallholders were not applying nitrogen at the estimated panicle initiation stage, which is often crucial to increase yield, and the majority (82%) of smallholders were applying phosphorus throughout the growth stages, when earlier applications are desirable. Smallholders may be able to reduce the cost of labor by reducing the number of P applications and avoiding late applications.

Key words: smallholder; fertilizer; decision making; Myanmar.

5.1 Introduction

Myanmar is an agricultural country with an abundance of natural resources and substantial potential for development. The agricultural sector plays a vital role in the country's economy, contributing 38% of the country's GDP (Gross domestic product), accounting for 25–30% of total export earnings and employing more than 60% of the labor force (World Bank, 2015). Despite this, agricultural productivity in Myanmar is low and farm profits are amongst the lowest in Asia (Findlay et al., 2015).

During the Green Revolution, new plant varieties plus modern agricultural technologies such as utilization of fertilizers along with policies supporting price and investments in seed technology, irrigation, roads, and extension were the main factors to boost agricultural production (Hazell, 2009). Fertilizer application is an important strategy in increasing crop yield (Hirel et al., 2011). It has been responsible for an average of 30 to 50 percent increase in yield in the USA and England and much higher increases in the tropics (Stewart et al., 2005). According to the World Bank (2017), the use of fertilizer in crop production has increased world-wide crop yields by 40 to 60 percent. Nitrogen (N), phosphorus (P), and potassium (K) are the major elements necessary to boost agricultural plant productivity and quality (Place et al., 1970). N is needed for plant growth as it increases protein content and grain yield (Kropff et al., 1993). P is required during early growth stages as it supports flower production, anthesis, grain setting, strong roots and stems, and ripening of plant (Place et al., 1970). K affects the number of spikelet per panicle, percentage of filled grains and grain weight, and increases plant tolerance to adverse climatic conditions, lodging, insect pests, and diseases (Dobermann and Fairhurst, 2000).

According to the 2016 World Bank database, the use of fertilizer in Myanmar is estimated at 17.9 kg/ha of arable land which is low compared to neighboring countries such as 289 kg/ha in Bangladesh, 503 kg/ha in China, 166 kg/ha in India, 162 kg/ha in Thailand and 430 kg/ha in Vietnam (World Bank, 2021). Other reports have documented the use of fertilizer by smallholders in Myanmar:

- Maclean et al. (2013); Rice Almanac (2013)–33 kg product/ha (5 kg NPK/ha)
- FAOSTAT (2018)—48 kg Urea/ha (22 kg N/ha)
- Gregory et al. (2014)—56 to 71 kg Urea/ha (36–44 kg N/ha)
- Denning et al. (2013); Garcia et al. (1998)–59 kg product/ha (27 kg N/ha)
- Naing et al. (2008)—76 kg product/ha (35 kg N/ha)
- LIFT (2016)—115 kg product/ha (53 kg N/ha, 15 kg P_2O_5/ha, 3 kg K_2O/ha)

A household survey conducted by Stuart et al. (Stuart et al., 2016) in Bago observed very low levels of N use due to uncertainty in fertilizer decisions and suggested that N application rates were one of the reasons for the rice yield gap. According to the Livelihoods and Food

Security Funds (LIFT) (2015), most fertilizer decisions in Myanmar are made based on observations and advice of other farmers in the village. A survey by the International Fertilizer Development Centre, IFDC (2015) stated that Myanmar farmers have strong demand for fertilizer but they have very limited understanding of the correct balance between plant nutrients and maintaining soil fertility, with restricted access to affordable credit. On the other hand, there are concerns over the national data quality with very limited representative survey data (Haggblade et al., 2013; Weil, 2017). Therefore, in this study we tested whether the reportedly low levels of fertilizer use by smallholders are generally true for central Myanmar by comparing it with national government agricultural agency recommendations.

The rates in Table 14 show the national recommended rates provided by the Land Use Division, Department of Agriculture (DoA) (Nyi, personal communication, May 8, 2020) and Agricultural Extension Division, Ministry of Agriculture and Irrigation Myanmar (MOAI) (MOAI, 2006). These general recommended rates are aimed at achieving a target yield of 5.2 t/ha for rice and 4.9 t/ha for maize.

Table 14. Recommended fertilizer application rates from national government agricultural agencies

Recommended fertilizer application rates from Land Use Division, DoA (2020)				
Crop	**Soil Test Value**	**Urea kg N/ha**	**T Super kg P_2O_5/ha**	**Potash kg K_2O/ha**
Rice	Low	102	27	117
	Medium	90	22	59
	High	57	11	15
Maize	Low	187	92	152
	Medium	176	86	95
	High	142	27	22

Recommended fertilizer application rates from Agricultural Extension Division, (MOAI, 2006)					
Crop	**Application**	**Manure Ton/ha**	**Urea kg N/ha**	**T Super kg P_2O_5/ha**	**Potash kg K_2O/ha**
Rice	Basal	2 to 6		51	
	Split (3 times)		86		112
Maize	Basal	7	29	57	37
	Split (2 times)		57		36

To achieve economic, social, and environmental goals, the global 4R Nutrient Stewardship Framework, developed by the fertilizer industry, has also stated that "Right Time" of fertilizer application is also important (Johnston and Bruulsema, 2014). The timing of fertilizer applications can significantly influence yields and profits of rainfed and irrigated rice farms (Saito et al., 2015; Wang et al., 2017). For example, on-farm testing of fertilizer recommendations in Senegal increased irrigated rice yields by 1 to 2.3 Ton/ha and profitability by 216 to 640 USD/ha (compared to farmer practices) (Saito et al., 2015). Much of the observed yield and profit increase was attributed to different fertilizer timing (Saito et al., 2015). Changing the timing of fertilizer application has environmental impacts such as pollution of water systems and emissions of potent greenhouse gases (Byrnes, 1990). Unlike the rate of fertilizer, farmers rarely need to invest more capital to improve fertilizer timing. In this study, we compared the fertilizer application timing practices of smallholders with the recommended "good management practices".

Several researchers have analyzed factors affecting farmer decisions on fertilizer use intensity. They found that fertilizer adoption is affected by prices, marketing, credit access, agro-climatic conditions, and farmer characteristics. Characteristics of the farmer or farm such as age, education, farming experience, and farm resources have been found to be important (Adesina and Zinnah, 1993; Chianu and Tsujii, 2004; Coady, 1995; Feder et al., 1985; Nkamleu and Adesina, 2000). Social scientists have argued for considering farmer perceptions in influencing adoption behavior (Koundouri et al., 2006). The uncertainty in yield responses to added fertilizer as well as the time of application remain important in farmer decision making (Majumdar et al., 2013). Therefore, this study investigated the perception of smallholders towards fertilizers and considers farmer motives and decision making to apply fertilizer in terms of two dimensions, namely, quantity applied, and timing of application based on a household survey of 600 smallholders in central Myanmar. It is widely noted that policy strategies for sustainable agriculture are best promoted by understanding the perceptions of those involved in the process (Rahman, 2003). Understanding the perceptions of smallholders regarding utilization and management of fertilizers, experiences, and their livelihood remains crucial in designing and implementing successful interventions. Such understanding will help inform strategies aimed at enhancing productivity and profitability of smallholders in Myanmar. The results from this study are valuable in clarifying how fertilizer management is being conducted by smallholders. Moreover, this is the first substantive study to compare and clarify how fertilizer management is being conducted by Myanmar smallholders and provides a sound basis for further research and development and agricultural policy considerations in Myanmar.

5.2 Methods

A household survey was conducted during May to July 2018 to collect data on fertilizer management by smallholder farmers in central Myanmar. In this study, the term "smallholders" is used for farmers who not only possess relatively small plots of land but are generally less well-resourced than commercial-scale farmers, practice farming as a main livelihood activity, depend on family labor and/or may hire workers, and are often vulnerable in the supply chain (Ethical Trading Initiative, 2005). Myanmar's agricultural sector largely comprises smallholder farms between one and five hectares (LIFT, 2016).

5.2.1. Study area

The study area is based on the field trial sites of a project (ACIAR, 2016), studying soil and crop fertility management for cereal crops in central Myanmar. The average farm size of smallholders in central Myanmar is small with more than half of the farmers (54%) owning less than five hectares and 83% less than 10 hectares (Mercy Corps, 2018). Field trial sites were established in three townships: Tatkon (1 site), Zeyarthiri (2 sites) and Taungoo (1 site) (Figure 19). This study contributes to the project and focusses on the population of smallholders in these townships surrounding the project trial sites, shown by black dots in Figure 19.

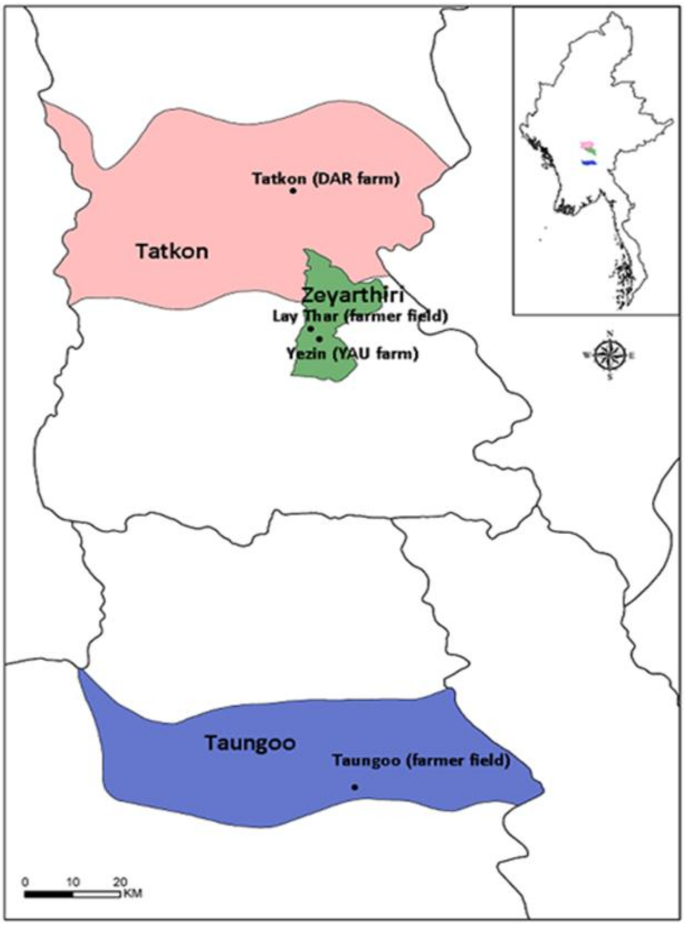


Figure 19. Study area, townships and trial sites in central Myanmar

5.2.2 Household survey sampling

A multi-stage sampling technique (Sukhatme et al., 1984) was used to select the sample and the respondent smallholders. In the first stage, grids of 1000 m × 1000 m were overlaid for each trial site. The purpose of the grid was to identify villages that would provide representative contextual settings from which to access farmer opinions and practices regarding fertilizer use. Then, within the grids, we identified village tracts, which are combinations of villages and the villages included in the selected village tracts. The villages were selected based on the number of farmers and the distance to the trial sites. Ten villages were selected from each township, providing 30 villages in total.

The total number of farmers within the grid for each township was identified with the help of the local DoA extension officers. To generate a representative sample of the farmer populations in each township, a 20:1 sample-to-item ratio (Costello and Osborne, 2005) was used. The questionnaire contained 30 items/topics; hence, 600 respondents were randomly selected for the study (Memon et al., 2020). In order to have equal respondents from each township, 6% of the farmers from each township were specified, comprising 258 respondents in Tatkon, 196 respondents in Zeyarthiri and 146 respondents in Taungoo.

A stratified systematic sampling technique (Levy and Lemeshow, 2013) was used to randomly select the sample. Farmer population was stratified by crop type and gender. Farmers cultivating the focus cereal crops (rice and maize) were selected. The criteria for the sample farmers included those who were head of the household, were the household member who led the farm work, or were actively cultivating land either as a landowner or land tenant and were available and willing to participate. A ratio of 8:2 for male and female farmers was selected based on the gender ratio within the population in the study area.

5.2.3 Data collection

A structured questionnaire was used to collect data from 600 farmers. The questionnaire included questions about socio-economic characteristics of the household, crop production information including crops grown, management practices, inputs and labor used, crop yields, marketing information and financing information such as borrowing amount, sources of credit, and interest rate. Also included were questions specific to each farmer about fertilizer management practices and decisions. The questionnaire was structured to understand how farmers make fertilizer decisions, their perception towards fertilizers, and management practices. The survey was conducted using CommCare®, a mobile application for data collection *(Flaming et al., 2016)*. A questionnaire was initially drafted and built in the CommCare HQ and then deployed to mobile phones/tablets. Survey enumerators were used to conduct the survey with CommCare®. The draft questionnaire was pre-tested with 10 non-sampled farmers.

5.2.4 Analytical methods

We compared the fertilizer practices and application rates against the national recommendation by the DoA and MOAI given in Table 14. The fertilizer timing practices were compared with generalized "good management practices", which were synthesized from peer-reviewed and mostly on-farm research on rice fertilizer timing. The "good management practices" in Table 15 are a synthesis which is unvalidated and may not be best in individual situations.

Table 15. Generalized "good management practices" for rice fertilizer amounts and timing

"Good practice"		Threshold	Supporting references
1.	Limit early N applications	Apply <1 third of applied N before 21 days (if direct seeded) or 14 days (if transplanted) after planting.	(Banayo, Bueno, et al., 2018; Buresh et al., 2019; Haden et al., 2011; Peng et al., 2010; Qi et al., 2012; Saito et al., 2015; Sharma et al., 2007; Silva et al., 2017)
2.	Avoid late N applications	Apply <5% of N <55 days before crop maturity for non-hybrid variety.	(Banayo, Bueno, et al., 2018; Fairhurst et al., 2007)
3.	Split apply N	Apply N at least three times (including basal application).	(Banayo, Bueno, et al., 2018; Buresh et al., 2019; Fairhurst et al., 2007; Saito et al., 2015; Silva et al., 2017)
4.	Apply N at panicle initiation	Apply 20 to 60% of applied N between 55 to 65 days before crop maturity.	(Banayo, Bueno, et al., 2018; Banayo, Haefele, et al., 2018)
5.	Apply P early	Apply all P within 14 days of transplanting or 21 days of direct seeding.	(Fairhurst et al., 2007; MOAI, 2006)
6.	Apply P once	Apply P once (including basal application).	(Fairhurst et al., 2007; MOAI, 2006)

Survey respondents with missing data for critical variables were excluded from analysis. For example, respondents who transplanted rice were excluded from analysis of "good management practices" #2 and #4 because data for seedling age at transplanting were required and unavailable for estimating time of panicle initiation (Buresh et al., 2019). We assumed all applied N and P were in the form of mineral fertilizer. Few respondents reported application of organic fertilizers, and these were typically in small quantities and areas. We also assumed all applied compound fertilizers contained 15% N and P as the nutrient composition of most compound fertilizers sold in Myanmar is N:P_2O_5:K_2O (N:P:K) 15:15:15. Finally, we truncated the number of urea or compound fertilizer applications to the maximum of three. Very few respondents reported four applications of the same type of fertilizer.

5.3 Results and Discussions

Smallholders in Myanmar have used fertilizers since 1965 when they were first introduced into the country, but widespread use did not occur until 1978 when fertilizer prices were subsidized by the government (Lwin et al., 2014).

5.3.1 Perceptions about and factors influencing fertilizer decisions

We first asked about the perceptions of smallholders in central Myanmar concerning use of fertilizer for crop growth (see Table 16).

Table 16. Farmers' perceptions about fertilizers

Fertilizer	Question	Response	% Overall
Users (n=594)	Do you think fertilizer increases crop yield?	Yes	93%
		No	6%
		Do not Know	1%
	Do you want to use more fertilizers?	Yes	72%
		No	28%
	Is fertilizer quality important?	Yes	99%
		No	1%
	Are you happy with the quality of the fertilizers you are currently using?	Yes	89%
		No	11%
	Who makes fertilizer decisions?	Male	55%
		Female	12%
		Both	33%
Non-users (n=6)	Do you want to start using fertilizers?	Yes	33%
		No	67%

Ninety-three percent of farmers considered that fertilizer increases crop yield, and 99% agreed that fertilizer quality is important. Seventy-two percent of the surveyed farmers stated that they wanted to use more fertilizers than the rates they were applying. Farmers were asked to specify the barriers preventing them from using the desired amount and the responses can be summarized into three main factors: lack of credit, limited repayment time, and uncertainty of seasonal weather patterns. With respect to the fertilizer quality, 89% of the surveyed farmers were happy with the quality of the fertilizers which was consistent with the findings from Nyi et al. (2017), who reported that most commercial fertilizers in local markets are true to label. Fertilizer decisions are made mostly (55%) by males with 33% making joint decisions (males and females together).

Farmer perceptions about fertilizer application practices are in Table 17. Most of the sample agreed or strongly agreed that basal applications and split applications are important, and that fertilizer is important for plant growth and tillering.

Table 17. Farmers response to fertilizer application practices

Questions	**Response (%)**				
	Strongly agree	**Agree**	**Neither agree/ disagree**	**Disagree**	**Strongly disagree**
Do you think you can receive higher yield with basal application of fertilizer?	13%	62%	1%	23%	1%
Do you think it is best to use split application of fertilizer?	23%	73%	1%	3%	0%
Do you think urea fertilizer boosts plant growth and tillering?	20%	69%	1%	10%	0%

The factors affecting farmer fertilizer decision making are in Table 18. Among the respondents, 42% stated that decisions on the rate and time of fertilizer application are made based on their personal decision depending on their experience. When deciding the choice of fertilizer to use, farmers rely mostly on popular brands (45%). Only 9% of the smallholders stated that price is considered in deciding the type of fertilizer, because most farmers explained that they have no control over the fertilizer price and would choose to apply good quality fertilizer regardless of the price because they consider that yields can increase by 5% to 50% by using fertilizers. This finding was consistent with a study in northern China (Zhou et al., 2010).

Table 18. Factors affecting farmers' decisions on fertilizer

Questions	Responses	(%)
How do you decide what type of fertilizer to use?	Use popular brands	45%
	Use what neighbouring farmers are using	28%
	Use what fertilizer retailers suggest	12%
	Low price	9%
	Use what agricultural extension officers suggest	6%
How do you make decision on how much or how often to apply fertilizer?	Personal decision	42%
	Suggestion from other farmers	24%
	Recommendation from fertilizer companies	15%
	Recommendation from agricultural extension officers	17%
	Fertilizer package labels	2%

The supply of fertilizer in the surveyed areas is reported to be adequate, with smallholders having one to five fertilizer suppliers or retail shops to choose from. Most have one or two regular suppliers. Ninety-two percent of farmers can buy the required amount of fertilizer at the required time, and most (93%) were happy with their current suppliers. Some smallholders change supplier depending on the delivery waiting period, up to 10 days. Accessibility is important as smallholders prefer input suppliers located in/near the village so that it is cheaper for transportation and easier to get credit for repayment after harvest.

5.3.2 Fertilizer use

Of the 600 smallholders interviewed in our study, 99% used fertilizers. Most smallholders reported that they use urea and compound fertilizers for rice and maize. Fertilizers were applied as basal and split applications. Basal applications are applied a day prior to sowing or planting, while split applications are applied after sowing/planting once the plants are established (Pandey, 2010). Broadcasting, in which fertilizers are spread across the surface of the crop field by hand (Rahman and Zhang, 2018), was the method used to apply fertilizer by most farmers due to lack of alternative methods.

5.3.2.1 Basal fertilizer application

When applying basal doses, compound fertilizer was mainly used with 26% applied to monsoon rice, 25% applied to summer rice, and 79% applied to maize. Urea fertilizer was not used as basal fertilizer application by smallholders in the study area.

The average basal fertilizer application rates applied by surveyed smallholders compared with the recommended rate from Agricultural Extension Division (MOAI, 2006) are shown in Table 19.

Table 19. Basal compound fertilizer and manure applications compared to recommended rates

Crops	Farmer Application Rates		Recommended Application Rates[a]			
	Manure Ton/ha	Compound Kg NPK/ha	Manure Ton/ha	N	P_2O_5	K_2O
Monsoon Rice	1.4	14	2 to 6		51	
Summer Rice	1.2	13	2 to 6		51	
Maize	2.1	17	7	29	57	37

[a] From Table 14.

Although 79% of the farmers cultivating maize reported that they use basal fertilizer applications, the rates that they apply were very low compared to the rates recommended by MOAI (2006). The amount of manure applied by survey farmers was also found to be lower than the recommended rates for both rice and maize crops. This is due to a decline in number of cattle associated with increased mechanization; one farmer stated "We no longer used oxen for ploughing anymore as it is more efficient to use tractors. Farmers who normally owned six oxen will now have two or none at all".

5.3.2.2 Split fertilizer application

With respect to split fertilizer application, most smallholders agreed that it is best to practice split fertilizer applications rather than applying once, although the number of applications varied according to the type of crop and the type of fertilizer (Figure 20).

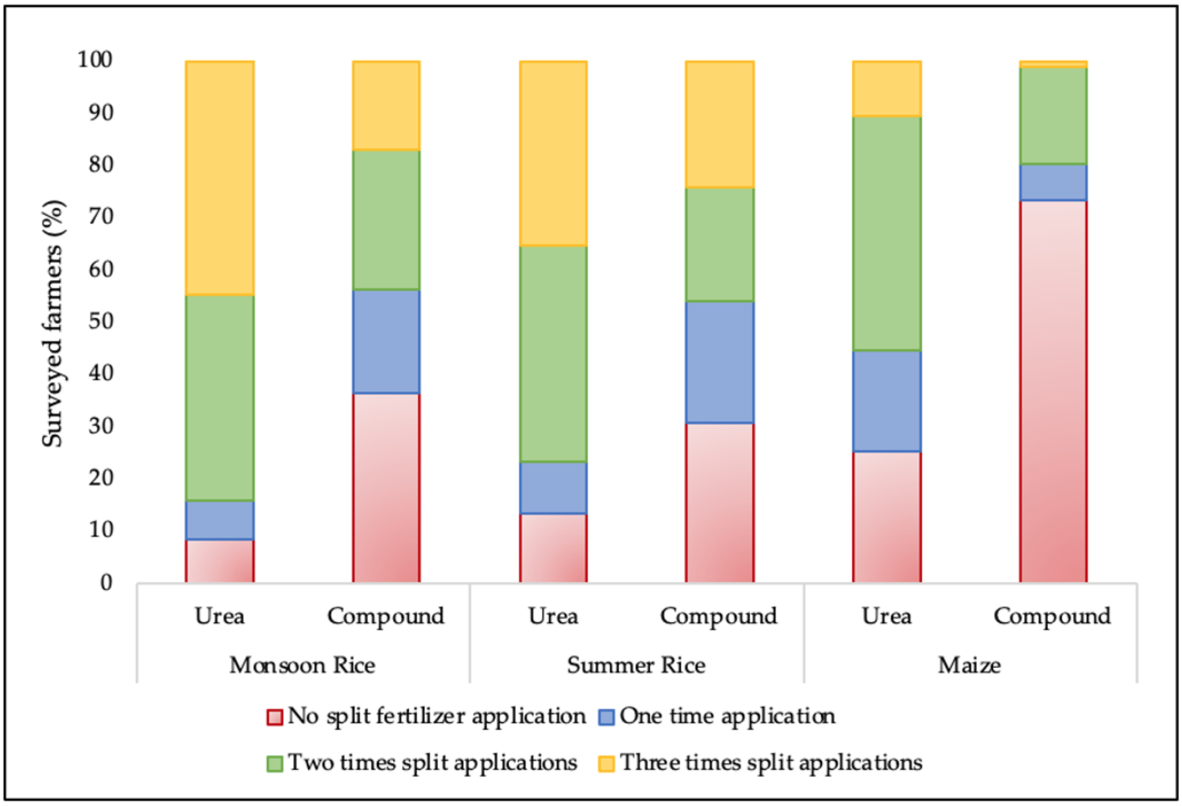
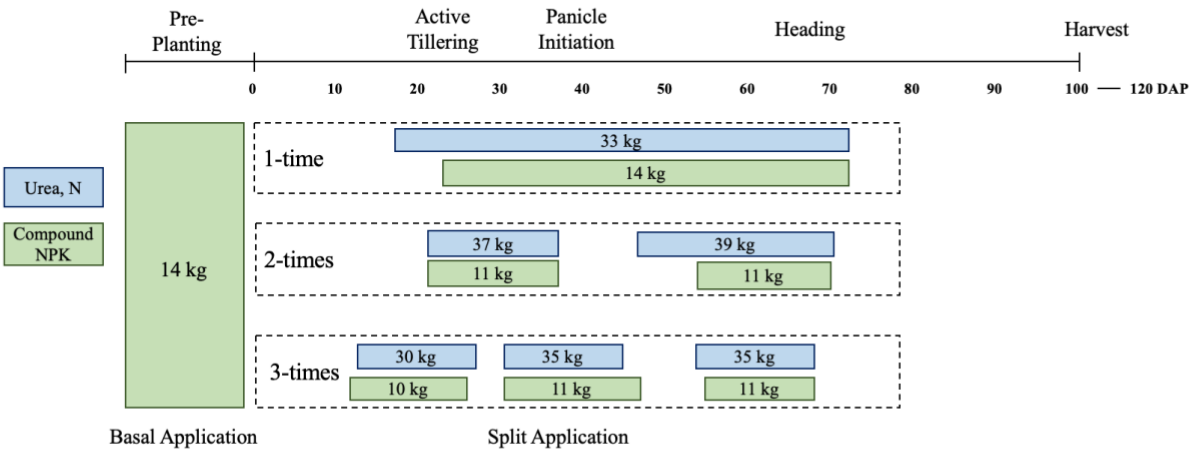


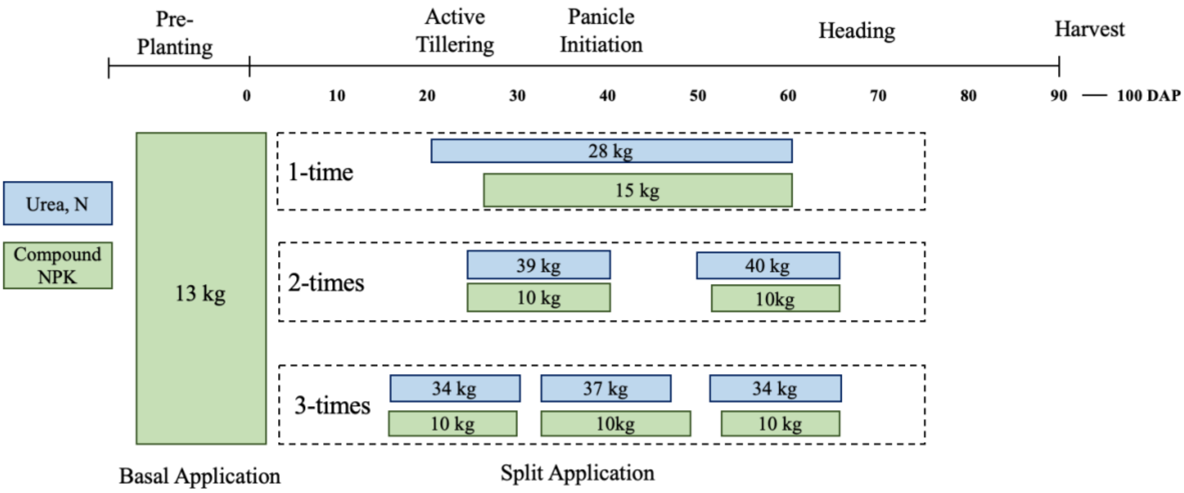
Figure 20. Split application of fertilizer based on the type of crop and fertilizer

For monsoon rice, most farmers applied urea two or three times after sowing/planting. The use of compound fertilizer was practiced by 64% of the smallholders growing monsoon rice. For summer rice, 86% of the fertilizer used urea and 69% of the farmers used compound as split applications. For maize, most smallholders were split applying urea fertilizer while very few farmers practiced split application of compound fertilizer, as many were applying as basal application.

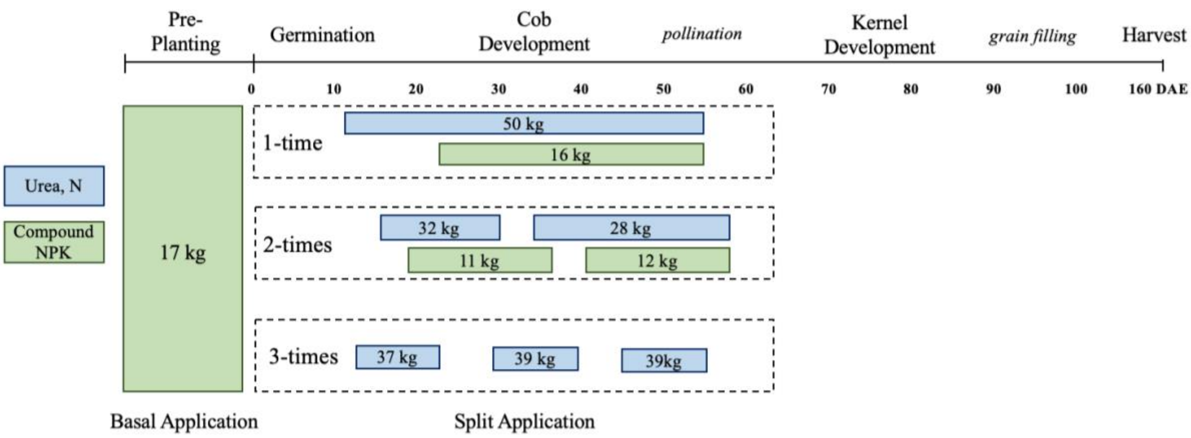
The average amounts of fertilizers applied by the surveyed farmers, based on the number of split applications over various time periods, are in Figure 21 for each crop type.



A. Monsoon Rice



B. Summer Rice



C. Maize

Figure 21. Average fertilizer application rates for each number of split applications at different times for monsoon rice
(**A**), summer rice (**B**), and maize (**C**); DAP = days after planting; DAE = days after emergence.

Most smallholders applied fertilizer at the tillering and flowering stages of rice with some farmers applying after panicle initiation (Figure 21A,B). For urea applied to monsoon rice, 45% of surveyed smallholders applied an average of 100 kg N/ha in three applications. Thirty-nine percent applied 76 kg N/ha in two applications, 7% applied 33 kg N/ha in one application and 9% applied no urea fertilizer. For compound fertilizers, 17% of the surveyed farmers applied 32 kg/ha in three applications, 27% applied 22 kg/ha on two applications, 20% applied 14 kg/ha once and 36% applied no compound fertilizer. These are average amounts applied in units of nutrient rates (i.e., kg/ha of N, P, or K). For summer rice, the application rates were similar to monsoon rice for both urea and compound fertilizers.

For maize, smallholders applied fertilizer during cob development with some applying till pollination (Figure 21C). Forty-five percent of farmers applied an average of 60 kg N/ha as urea in two applications. These results generally imply that these smallholders apply substantial amounts of fertilizer to cereal crops and the rates are significantly higher than previously reported rates in Table 14.

The distribution of urea fertilizer application rates by the surveyed farmers was compared with the national recommended rates provided in Table 14. For this comparison, we used recommended rates of 86 to 90 kg N/ha for rice (MOAI, rice split 3 times (86 kg N/ha) and DoA median soil test value (90 kg N/ha)) and 176 kg N/ha for maize (DoA medium soil test value). The comparisons are in Figure 22.

Monsoon rice was cultivated by 89% of the smallholders in the survey sample. Twenty-three percent of farmers were applying within the range of 69 to 92 kg N/ha while 47% of the farmers were applying lower and 30% of the farmers were applying higher than the recommended rates (Figure 22). Nine percent of farmers applied no urea fertilizer.

Summer rice was cultivated by 22% of the farmers in the survey due to limited access to irrigation and only 20% applied urea fertilizer within the recommended range, while 49% of the farmers were applying lower and 31% higher than recommended rates.

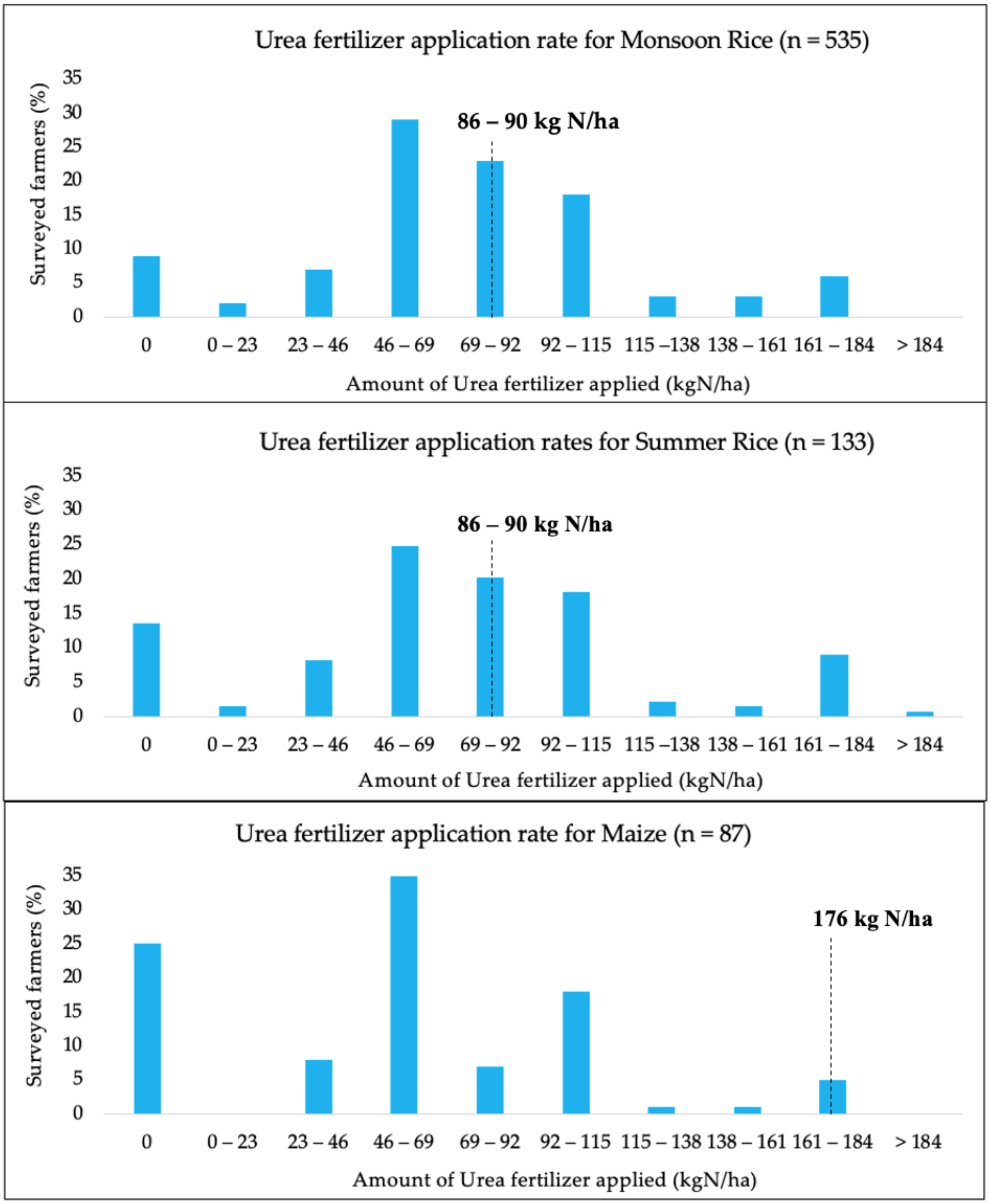


Figure 22. Distribution of urea fertilizer application rates by surveyed farmers compared with national recommendation
(---represents the national recommended urea fertilizer application rates from Department of Agriculture (DoA) and Ministry of Agriculture and Irrigation (MOAI)).

While there were smallholders applying substantial amounts of fertilizer in the study area, there were also some farmers applying no fertilizer, or less than the recommended rates, and some who were applying urea fertilizer at higher rates to their rice crops. While the low use of N fertilizers is a sustainable challenge to increase the overall food production, especially in developing countries where production is required to be doubled (FAO, 2009), high use of N fertilizers is regarded as unsustainable for the environment since it can lead to air pollution, degradation of water quality, damage to soil, and fertilizer waste (Deckers and Steines, 2004; Liu et al., 2009). Hence, the concept of sustainability provides the definition of "right" in the source, rate, time, and place of application which conveys how fertilizer applications can be managed to achieve economic, social, and environmental goals (Reetz et al., 2015). Rahman and Zhang (2018) reported that fertilizer placement is one solution for sustainable fertilizer management in Bangladesh and can be utilized by Myanmar smallholder farmers, given the similar socioeconomic and demographic status. Site-specific nutrient management (SSNM), such as urea deep placement (UDP), is a one-time application that allow plants to access N when required (Johnston and Bruulsema, 2014) and has been introduced to Myanmar farmers since 2014 (Aung et al., 2017). However, adoption of SSNM has been slow and was not observed by farmers in the study area.

Maize was cultivated by only 15% of farmers in the survey. With respect to urea fertilizer application, 25% of the farmers did not apply any urea fertilizer and 95% applied less than the recommended rate. The practice of low fertilizer use on maize has also been observed in other countries (Karkia et al., 2020; Ogeto and Jiong, 2019). Maize is typically known as a heavy feeder crop and increased fertilizer application is necessary to increase productivity (Adhikari et al., 2016). Many African countries have adopted fertilizer subsidy programs to encourage fertilizer use after the success of the program in Malawi (Jayne and Rashid, 2013). Although these subsidy programs were successful in increasing fertilizer use, improvements in yield were very limited (Liverpool-Tasie et al., 2017; Scheiterle and Birner, 2018). Increases in crop yield depend not only on the use of fertilizer. Other factors preventing higher yields include unavailability of suitable high-yielding varieties (HYVs), poor infrastructure and related high transport costs, inadequate institutional support (extension), political instability, and diverse agro-ecological complexities, including climate change (Denning, 2009; Evenson and Gollin, 2003).

5.3.2.3 Economic considerations

The national recommended fertilizer rates in Table 1 are based on soil and agronomy targets and may not include the economic dimensions of farm-level decisions (Anderson et al., 1977; Anderson and Hardaker, 1979; Roumasset, 1976). Studies have discussed the economics of optimum fertilizer inputs (Kennedy, 1981; Lanzer and Paris, 1981; Roumasset, 1976). Anderson (1975) noted that the level of net benefit is small when management practices are varied within the optimal region because the economic profit functions are relatively flat. Pannell (2006) also described the economic pay-off functions for many agricultural inputs as being relatively flat around the optimum. The implication of flat rate pay-off functions is that it is unnecessary to be precise about the optimal rate of an input such as fertilizer at the top of the input–profit response curve. This allows for flexibility for farmers to adjust rates by considering other factors such as risk, labor, soil type, climate, and availability of finance or environmental impacts. Farquharson (2006) accommodated the flatness of response issue by requiring a minimum target Return on Investment (ROI) (or Marginal Rate of Return) for cereal fertilizer decisions. In the face of uncertainties "it is better to be approximately right than precisely wrong" (Keynes, 1936). Despite the imprecision in assessing economic rates for fertilizer, accounting for the economics means that application rates are likely to be less than agronomic recommendations for maximum yield.

Farmers also react to uncertainties by adopting a level of input in the suboptimal region (for maximum economic profits) to avoid irrecoverable damage or loss (Jardine, 1975). Risk and risk aversion by decision makers have been used to describe the amounts of inputs used (Feder, 1980). Many authors have considered risk (Harwood et al., 1999; Roosen and Hennessy, 2003), risk analysis (Anderson and Hardaker, 1979; Hardaker and Lien, 2007) and risk in utility analysis (Dillon, 1971a), uncertainty and decisions in adopting new technology (Feder, 1980; Marra et al., 2003), processes of adaptation in farm decision making (Robert et al., 2016), managerial decision making (Dillon, 1971b; Samuelson and Marks, 2015), and approaches such as the use of intuition (Nuthall and Old, 2018) in making real-life decisions (Gladwin, 1980). Accounting for risk in farm decision making is important (Backus et al., 1997) when deciding or recommending input rates for fertilizer.

5.3.3 Fertilizer timing analysis for rice

The timing of fertilizer applications practiced by surveyed smallholders was compared with the six recommended timing "good management practices" for rice production described in Table 15. There has been no study in Myanmar considering the fertilizer application timing in cereal crops. The results are in Figure 23.

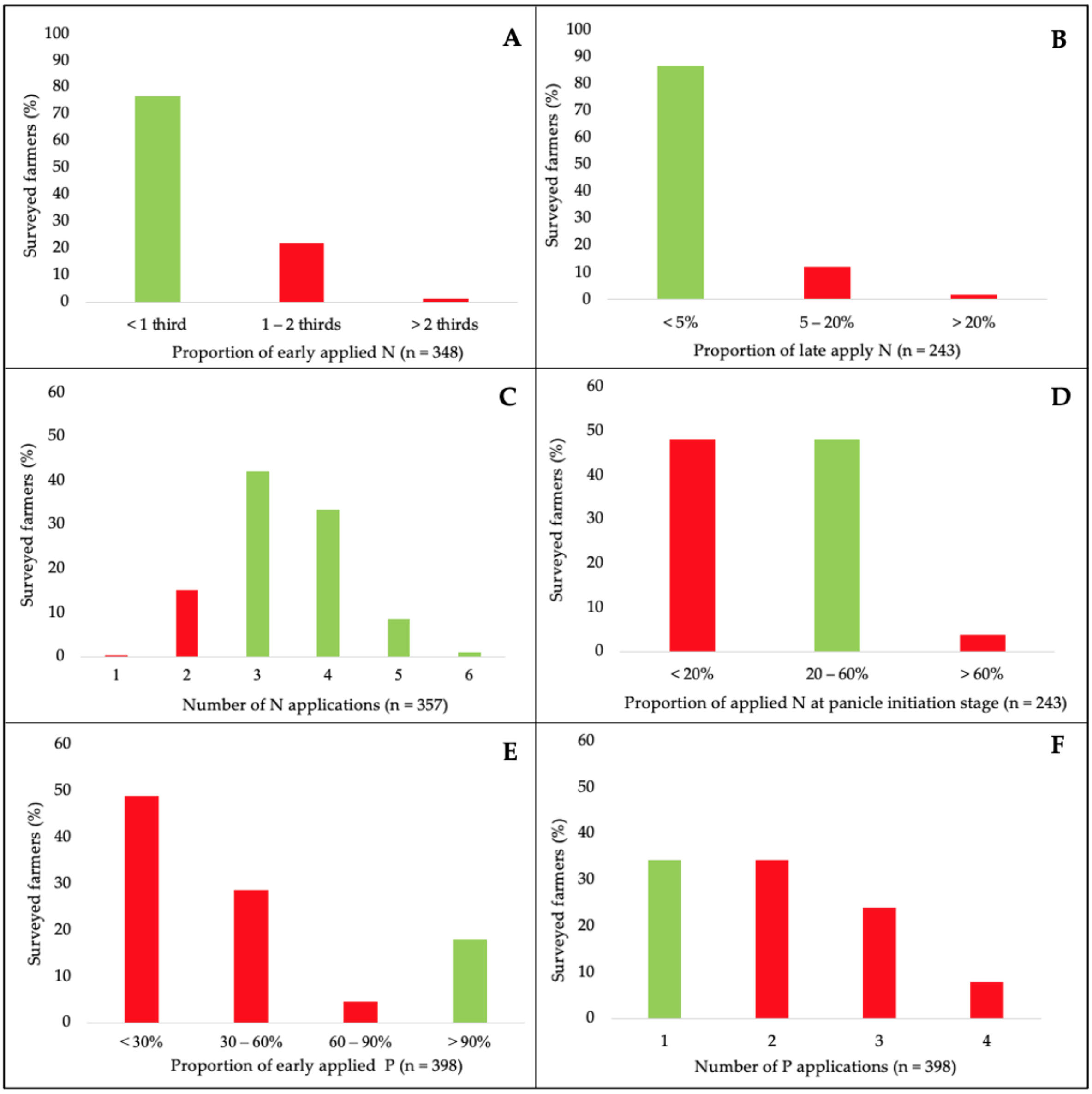


Figure 23. Timing of fertilizer application practices by surveyed rice farmers compared to "good management practices".
Graphs (A) – (F) refer to fertilizer management practices. Green columns represent practices that are aligned with the generalized "good management practices" and red columns represent those not aligned.

Most reported farmer practices were aligned with the first three "good management practices". More than 75% of analyzed farmers avoided excess early application of N (Figure 23A), approximately 90% avoided late applications of N fertilizer (Figure 23B), and approximately 85% applied N fertilizer at least three times (including basal applications). In this analysis, multiple applications on the same day or multiple basal applications were counted as one application (Figure 23C). The high number of N splits is mainly due to the high number of compound fertilizer applications. Thind et al. (2018) reported that increases in number of N applications beyond three did not increase yield in an Indian research trial. Hence, many smallholders could reduce the number of compound fertilizer split applications and save labor costs as it is likely to have negligible impacts on rice yield. In contrast, nearly half of the surveyed farmer practices did not align with the fourth analyzed "good management practices" (apply N at panicle initiation between 55 to 65 days before crop maturity) (Figure 23D).

When applying P, farmer practices generally did not align with the recommended "good management practices" (apply P during the early growth stages of rice as it supports flower, root, and stem development (Place et al., 1970)). Only 18% of the farmers applied total P early (within 21 days after seeding or 14 days after planting) (Figure 23E). Most farmers (82%) were applying P throughout the growth stages when it may have been needed earlier. It is also recommended to apply P only once as it is relatively immobile (Fairhurst et al., 2007; MOAI, 2006) and so the cost of labor for fertilizer application can be saved by applying only once. Only 34% of the farmers were found to be applying P once (Figure 23F).

Smallholders could improve the timing of fertilizer application if they stopped applying compound fertilizer and instead applied single nutrient fertilizer such as urea, T super, and potash when individual N, P, and K nutrients are needed throughout the crop growth stages. However, compound fertilizers also commonly contain micronutrients. The decisions on compound fertilizer applications appear to be associated with labor-saving considerations.

5.4 Policy Implications

The current fertilizer law in Myanmar focusses on fertilizer trade, registration and licensing, and quality control. Some implementing regulations are deficient in terms of completeness and clarity based upon international standards (IFDC, 2018). Agricultural policies in Myanmar have been focused on increasing yield by encouraging increased use of fertilizers (MOALI, 2018) but care should be taken to avoid excessive recommendations. From this study, 30–31% of the surveyed farmers were applying more than the recommended urea fertilizer recommendations for rice. Increased fertilizer use is necessary for sustainable intensification by reducing deforestation and preserving production potential of the land. However, it must be combined with land conservation (Holden, 2018). Application of fertilizer by the broadcasting method can lead to excessive use of fertilizers (Rahman and Zhang, 2018). Hence, blanket recommendations should be avoided, and SSNM practices should be encouraged. Accurate and accessible soil assessments combined with programs to increase farmer literacy on soil and environmental health will assist with fertilizer management. Studies on farm typology can distinguish specific farmer groups, based on the levels of fertilizer use, to enable training to increase smallholder fertilization knowledge and adoption of advanced fertilizer management technologies. Policies aimed at not only increasing fertilizer application but also reducing over-fertilization, are desirable. Fertilizer policies which emphasize the implementation of placement methods may be valuable.

Issues of sustainable development focus on three pillars, namely environment, economy, and society (Taylor, 2016). Porter and van der Linde (1995) implied that "the best choice for sustainability should meet the needs of society and are environmentally and economically viable, economically and socially equitable as well as socially and environmentally bearable". There is a trade-off between the three pillars where there is a choice between aiming for economic growth, environmental conservation, or social equality (Mensah, 2019). This trade-off is more prominent in developing countries where economic growth is commonly prioritized as the population needs money to survive and economic growth means more jobs in the economy (Ma and Jiang, 2019).

However, the reality in many countries, including Myanmar, is that reducing poverty and improving food security are the primary aims. The main objective of many projects from international organizations in Myanmar focuses on reducing poverty and improving food security (LIFT, 2014, 2016) with less attention on the environment. Focus on economic development, such as increasing yield for the growing population, can lead to increased use of fertilizers which inevitably causes pollution.

Policies can be developed to include a charge in the price of N for excessive use of chemical fertilizers. However, an integrated modelling approach by Wei et al. (2009) found that raising the price of N delivers little benefit to society and increasing the water prices is the better policy instrument. In Myanmar, the existing policy and administration of water resources is scattered and unfocused (AQUASTAT, 2011; Tun et al., 2015). Studies have found that one of the main reasons for farmers overusing fertilizers is due to lack of knowledge in the N application rates (Sonntag and Norse, 2005), and hence training and educational programs for sustainable fertilizer management may improve the sustainability of the agro-ecosystem.

From the study, 95% of the surveyed maize farmers were found to be applying less than the national recommended rates. Evidence from other countries has shown that fertilizer subsidy programs have been effective in increasing fertilizer use but have had little success in increasing yield. In particular, the Green Revolution productivity increases were predicated on using more N, while there is enough (irrigation) water and use of HYVs (Janvry et al., 2016). Although more N might be used through subsidies, if the crop varieties used are not able to fully express this enhanced fertility in increased crop yields, then the policy aim of yield improvement cannot be achieved. Farmers in the study area were found to be using CP888, a hybrid maize variety, which may help explain why an increase in N use might not lead to an increase in yield (Than et al., 2017). In the case of rice, farmers in the study area were found to be mainly using HYVs (Than et al., 2017); however, the quality of the HYVs may be of concern. In Myanmar, shortage of good quality seeds has been identified, with there being only about 10% of the supply of improved seeds and 90% from farmers' saved seeds from the previous season's harvest (Tun et al., 2015). There is a need for cost-effectively generating and delivering improved seed varieties to farmers. Hence, policies need to address more than just increasing fertilizer usage.

In Myanmar there is a limited credit supply for maize farmers from the Myanma Agricultural Development Bank (MADB). MADB is the largest institution financing agricultural activities at a subsidized interest rate (World Bank, 2014). However, it only finances farmers with formalized land tenure and to produce certain crops, and the amounts are specified by crop type. Maize farmers can only borrow USD 95 per ha, substantially less than rice farmers (USD 280 per ha). According to Fang and Belton (2020), this amount covers only 4% of the total maize production cost. This may explain the low use of fertilizer by maize farmers. A study by Tadesse (2014) provided evidence that the probability and intensity of fertilizer use increased significantly with better access to credit. Hence, there is a need for maize farmers to have better credit access and to identify ways of disbursing formal agricultural credit to smallholders without formal documentation of land tenure or title. Innovations to improve rural credit access are worth further study.

Another reason for the low use of N in maize compared to rice by farmers could be due to cash flow implications. The country's rice self-sufficiency policy has led farmers to consider that rice is a more important crop than any other crops (Cunningham and Munoz, 2017). This remained consistent with the survey results where rice was cultivated by 89% of the farmers while only 15% cultivated maize in the study area. Hence, when farmers have limited money for fertilizers, they will use the limited budget for N fertilizer primarily on rice.

Some limitations of this study need to be noted. Although the sample size of the study covers 6% of the population of the project area, the study location had greater than average access to input retailers and agricultural support services. The field trial locations were located at sites associated with or close to government research stations or university land. This provided easier access for local extension officers but not for all farmers. Study areas for further research could be located at remote and under-resourced areas covering a wider landscape. The study mainly focused on applications of urea and compound (N:P:K) fertilizers by smallholder farmers and did not consider other micro-nutrients, manure, and organic fertilizers. Further studies on these can be useful.

5.5 Conclusions

In this study we report results of a survey of 600 smallholders in central Myanmar. Smallholder perceptions that fertilizers increase cereal crop yields have been the primary motivation for fertilizer use. There are many types of fertilizer brands available in central Myanmar. When deciding which fertilizer to use, smallholders mainly rely on popular brands and opinions of other farmers. Most fertilizer decisions were made by male farmers. Fertilizer quality was not of concern to most of the smallholders.

The second part of the study highlighted the fertilizer practices of smallholders in the study area. We tested whether the reportedly low levels of fertilizer use by Myanmar smallholders are generally true in the study area. We compared their fertilizer practices to national agricultural agency recommendations. We also compared the timing of fertilizer application against recommended "good management practices". This is the first study to compare and clarify how fertilizer management is conducted by Myanmar smallholders, and the findings are valuable in discussing whether, and what type of, interventions could be developed.

The survey results revealed that 99% of the smallholders in the study area were using fertilizers. Smallholders understand the crop yield responses to basal and split fertilizer applications of N. They apply compound fertilizers to ensure that other nutrients, apart from N, are not limiting. The average N fertilizer application rates were generally found to be substantial for rice. Hence, the reported national-level data and farm-level research implying low fertilizer use by Myanmar farmers is not confirmed by this contemporary study in central Myanmar. However, the distribution of fertilizer applications showed that there were farmers applying no fertilizer and others were over-applying fertilizer. Only 20 to 23% of the surveyed farmers were found to be applying within the national recommended range of urea fertilizer in rice. Smallholders were found to be applying substantially lower N levels than the recommendations for maize.

But smallholders are rational; they have good reasons for doing what they do. Farmers applying no fertilizer may be in a subsistence mode and the others who are using fertilizers are in a semi-subsistence or commercial mode. An understanding of the economics and risk associated with farm-level decisions is important when considering practices of farm input usage by smallholders.

With respect to fertilizer application timing, smallholders' practices were generally aligned with the first three N timing "good management practice". However, nearly half of the surveyed farmer practices did not align with the fourth practice (apply to N at panicle initiation). This was an important recommendation for farmers in the study area in Myanmar. With respect to P timing, most farmers were applying throughout the growth stages, when earlier applications are desirable. Smallholder farmers may also be able to save the cost of labor for fertilizer application by reducing the number of P applications and avoiding late application. Overall, these farmers are using better fertilizer management than indicated by the literature and careful consideration is needed to improve smallholder fertilizer management.

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Chapter 6

Journal Paper 2

An empirical analysis of the use of agricultural mobile applications among smallholder farmers in Myanmar

This chapter has been published as follows:

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Abstract

Mobile phone applications (apps) designed to assist smallholder farmers improve decision making have been revolutionizing the agriculture sector. These apps offer solutions to farmer information needs by providing weather information, crop market trends, pest and disease damage identification, and advice on pesticide and fertilizer use. They also facilitate interaction with fellow farmers, extension workers and other stakeholders in the value chain who are interested in information exchange. Much previous research has investigated the contribution of mobile apps to agricultural production. This study explored the agricultural mobile apps available in Myanmar, analyzed factors affecting their use and assessed the potential for farm-based decision support. Our findings indicate that when introducing mobile-based tools, focus should be given to younger, more educated farmers growing more specialized crops. The main constraints to adopt agricultural apps are lack of access to smartphone and/or internet (63%) and lack of digital knowledge (20%). However, smallholder farmers in Myanmar were optimistic and positive towards agricultural apps for effective utilization. We also found that majority of the surveyed farmers were familiar with information received through Facebook groups. Incorporating useful information and functions from an agricultural mobile app to a Facebook Page could have a more useful and sustainable impact.

Key words: mobile application; smallholder farmers; decision making; Myanmar.

6.1 Introduction

In agriculture, access to relevant and timely information remains crucial for farmers. Farmers' access to up-to-date information such as weather, availability and market prices of farm inputs, and knowledge about innovative farm technologies can enhance farming productivity (Aldosari et al., 2017). With improvements in Information and Communication Technology (ICT), there is an increasing access to useful communication tools to help information delivery (Obong et al., 2018).

ICT tools such as mobile phones, in particular, are now an important resource to distribute information with potential to reach many farmers across rural settings (Santosham and Lindsey, 2015). Baumüller (2015) found that mobile phones are useful in providing timely information as well as the ability to store the information when farmers are selling their produce. Impacts on agricultural extension service delivery, including the amount, quality and speed of delivery, have improved significantly with mobile phone interventions (Fu and Akter, 2016). The benefits to farmers have been through greater knowledge and awareness of new information about agricultural practices. Furuholt and Matotay (2011) found that better access to market information that came with the use of mobile phones led to increased opportunities and reduced risks for rural farmers. A study based on data from 81 countries by Lio and Liu (2006) suggested that overall agricultural productivity has increased with the use of modern ICTs, which includes mobile phones and the internet. They found that adoption levels and the returns in developed countries were higher than those for developing countries, suggesting that increased use of ICTs could boost agricultural productivity in developing countries. According to Sanga et al. (2016) mobile phones and agricultural mobile apps can resolve deficiencies in agricultural extension service delivery systems when expanding outreach to remote areas.

Various agricultural mobile applications (apps) have been developed to provide farmers with information on weather (including flood and drought warnings), daily crop market trends and prices, pest and disease identification and advice on fertilizer use (Gichamba and Lukandu, 2012; Qiang et al., 2012; Romani et al., 2015; Woodill and Udell, 2012). Mobile apps are software programs that can operate on smartphones and tablets (Serrano et al., 2013). Daily weather updates and seasonal weather forecast are available to farmers through apps, which can help decisions about sowing, fertilizer and pesticide applications, and harvesting (Caine, 2015). In this paper, the term "agricultural mobile apps" is used to describe any mobile-based app that targets the needs of the agricultural sector and its stakeholders.

Mobile apps have become a preferred way of information dissemination compared to SMS texts with the widespread availability of smartphones (Kaske et al., 2018). In most cases, access to relevant information has a positive effect on farmers' decision-making ability

(Taragola and Lierde, 2010) and facilitates interaction with fellow farmers, extension workers and other actors through exchange of information (Narine et al., 2019). Agricultural mobile apps such as Agrowdata (USA), Agrivi (Europe), Cocoalink (Ghana), Green Way (Myanmar), and The Agronomist's Diary (Russia) have been reported as useful to farmers (Meirmanova, 2019). Prior to 2011 only a few apps were widespread and financially self-sustainable, and the support for agricultural development was limited (World Bank, 2011). A study by Costopoulou et al. (2016) observed that the supply of agricultural mobile apps is still in its infancy because they have low ratings in reviews, indicating that they do not meet agricultural stakeholders' requirements. It has also been found that despite various initiatives for farm information and knowledge transfer using mobile apps, the outcomes are not satisfactory because of the poor use of these apps (Barakabitze et al., 2017; Khan et al., 2010; Patel, 2016; Qiang et al., 2012). There is a need to explore the factors linked with the use of agricultural mobile apps.

6.1.1 Agricultural mobile apps in Myanmar

The agricultural sector in Myanmar plays a vital role in the country's economy, contributing 38% of the country's GDP, accounting for 25-30% of total export earnings and employing more than 60% of the labor force (World Bank, 2017). However, the agricultural extension services are weak and under resourced (Haggblade et al., 2013) and practice a "traditional extension approach" focusing on individual contacts mainly with "progressive farmers" who are generally resourceful and easiest to reach. Many other smallholder farmers have limited and inadequate information about improved technology such as good quality seeds and fertilizers, crop management and farming techniques (Cho, 2013; Oo and Ando, 2012; Win et al., 2018).

In Myanmar, smallholder farmers dominate the agricultural sector with 80% of the farmers each owning less than 5 ha of land (Kyaw et al., 2018). For the purpose of this study, the term "smallholder farmers" is used for farmers who not only possess relatively small plots of land but are generally less well-resourced than commercial-scale farmers, practice farming as a main livelihood activity, depend mainly on family labor and/or may hire workers, and are often vulnerable in the supply chain (Ethical Trading Initiative, 2005). Hence, it is important that these smallholder farmers have easy access to information in a timely manner to improve their productivity.

Mobile phone usage in developing countries, such as Myanmar, is also expanding at a rapid pace. According to Telenor (2018), Myanmar was one of the world's fourth fastest growing telecommunication markets with mobile phone ownership estimated to be 80% of the total population. Internet used has also increased from 1% in 2001 to more than 30% in 2018 (McLaughlin, 2018). This provides opportunities for smallholder farmers in using mobile phones to obtain information in support of farm decision making and rural development (Chhachhar and Hassan, 2013). There are five agricultural mobile apps currently available in Myanmar.

The Green Way Agri-Livestock App is an agricultural and livestock app designed for use by farmers and others in the agricultural sector. The app includes information on farming practices, livestock management techniques, weather forecasts, daily crop market trends and prices, and contains a question-and-answer section where agricultural technicians can provide farmers with effective solutions to farmers' problems. The app creates linkages between farmers, agronomists and Department of Agriculture (DoA) extension officers to provide information for more than 60 crops. However, the app can only be used where internet connection is accessible. According to the official Greenway app website (http://www.en.greenwaymyanmar.org/) there were 100,588 active farmer users in 2019, of which 17% were women farmers and there were 2,873 technicians.

The Ooredoo Site Pyo has been developed by Ooredoo, one of the leading mobile operators in Myanmar (Ling et al., 2015). In March 2016, Ooredoo launched an agricultural smartphone app called Site Pyo, meaning "Cultivation" (GSMA, 2017) providing valuable information for Myanmar farmers about increasing crop yields. Ooredoo Site Pyo app is free to download and does not require internet connection, making it attractive to farmers and other users. It provides information on seed quality control, land preparation, fertilizer and water management, weed control, pests and diseases guidance, and harvesting and storage. It also provides weekly weather forecasts and sends out emergency alerts. The app is designed to be used in both Myanmar and English languages. According to a case study conducted by GSMA (2017), among farmers using the app 81% reported at least one type of on-farm decision changed, 64% changed pest and disease control practices and 31% changed harvesting or post-harvest practices. In their study, 44% of users reported the mobile phone as one of the main sources of information leading to changes in farm practices. However, there were no significant effects of the Site Pyo app on productivity or income levels. The app is only available for use with Ooredoo SIM card, which was a promotional strategy of the mobile operator.

The Golden Paddy app, also known as "Shwe Thee Nhan" in Myanmar, is a free web and mobile app developed by Impact Terra, an agricultural technology social enterprise which provides digital services to farmers (www.impactterra.com/golden-paddy). Like other agricultural apps, it provides weather forecasts and best farming practices with recent agricultural news. It also provides information on input and product prices and information about sellers and financial institutions. The service can be used offline, and some aspects are offered through messages which direct to other functionalities.

The Htwet Toe app is another mobile app providing agricultural information to farmers. Htwet Toe means "higher yield" and is designed to help farmers increase their productivity and improve crop quality. It was developed by Village Link where a leading Myanmar agricultural cooperative, Myanma Awba Group, is a major stakeholder. Myanma Awba is also a well-known distributor of fertilizers and seeds throughout the country (Stads and Kam, 2007). Like the Green Way app, this app serves as a platform to connect with agricultural professionals, to ask questions and upload pictures through a live chat function. The app has been funded by the Dutch government to include more features such as yield predictions, seasonal weather forecasts and site-specific recommendations to support farmer decision making (Awba, 2018).

The Plant Protection (PP) mobile app has been developed by the Plant Protection Division of the Myanmar DoA. The app provides information specific to pest and disease management to promote the effective and safe use of pesticides on agricultural products. It contains information on integrated pest management for 25 crops, 187 insects and pests, 137 plant diseases, 30 different weed types and 12 rodents, as well as other useful information on different pesticides and use (www.ppdmyanmar.org/how-to-use-plant-protection-pp-mobile-application/).

All the apps require Android mobile phones and most of them require access to the internet which can incur some cost for the farmers, although the cost of downloading the app is free. The long-term sustainability of the apps can also be an issue as most of the apps are funded by individual projects. A list of the features in these apps is provided in Supporting Information Table A1. Features available in the agricultural mobile apps in Myanmar are summarized in Figure 24. The main uses are provision of information and means of communication for farmers with other interested parties.

Apart from apps designed to provide agricultural information, social media platforms such as Facebook have become very popular among participants in the agricultural value chain (farmers, input suppliers, retailers, and agricultural extension officer) as a place to interact and discuss agricultural and farming topics. For example, Myanma Awba, the largest manufacturer and distributor of agricultural technology such as fertilizers and seeds in Myanmar, hosts weekly discussions related to crop fertilizer management among Myanmar farmers. Currently the Myanma Awba Page has over 1.5M Facebook followers and has become an interactive forum for lively debates, solving farming related issues as well as a platform for exchanging knowledge and networking among industry stakeholders and farmers.

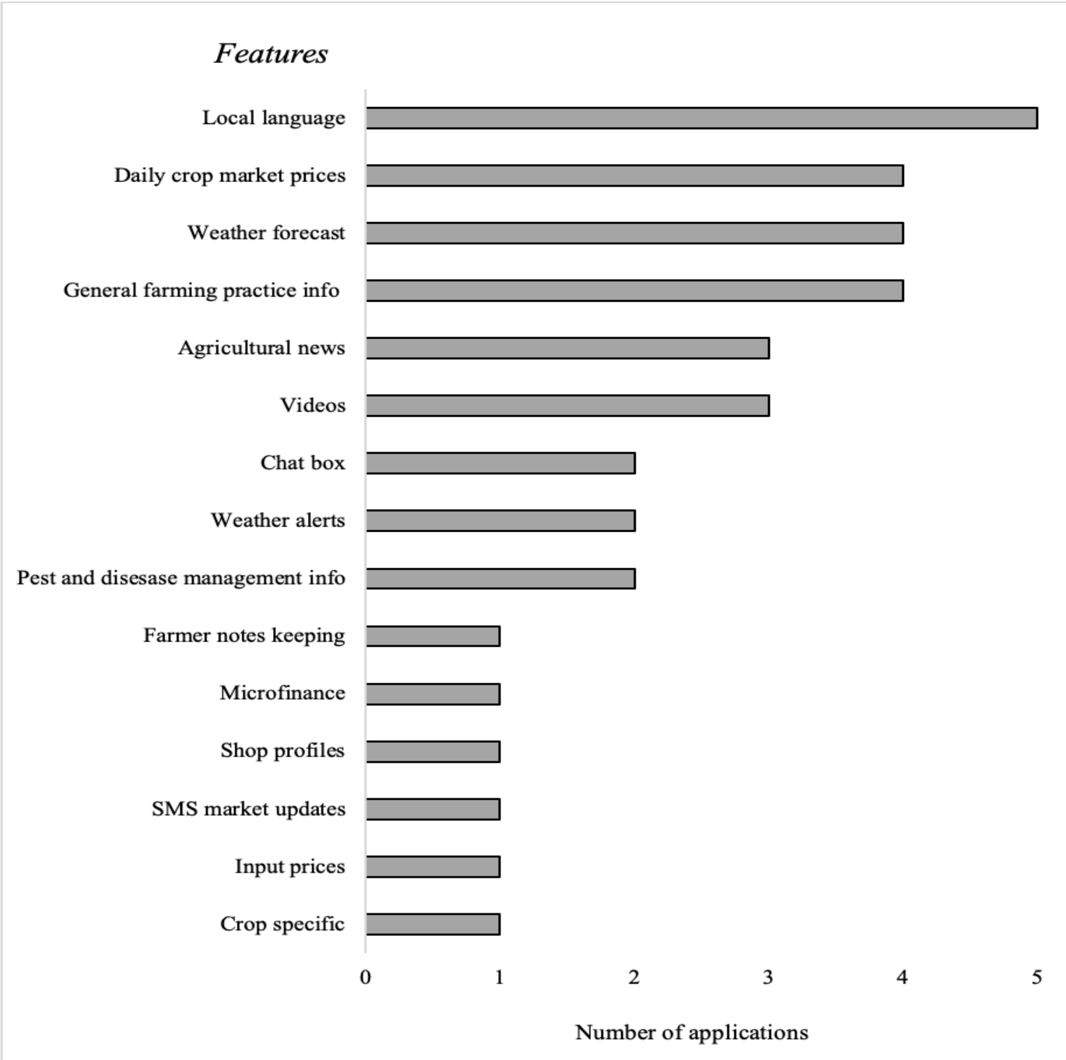

Figure 24. Features available in the agricultural mobile apps in Myanmar

6.1.2 Research objectives

Studies focusing on mobile phone applications and use in agriculture have been undertaken in many countries (Aker and Fafchamps, 2013; Aldosari et al., 2017; Brugger, 2011; Costopoulou et al., 2016; Meirmanova, 2019; Misaki et al., 2018; Patel, 2016; Qiang et al., 2012). However, in Myanmar very little literature relates to perceptions and use of ICTs and no study has considered factors related to the use and adoption of mobile apps in the Myanmar agricultural sector. Given the low uptake of decision support tools/apps by farmers throughout the world (Kerr, 2004; McCown, 2002), this paper provides valuable context for discussing farmer perceptions and what factors need to be considered in developing and scaling up mobile applications.

The present study considered the following research objectives:

1. Assess the smallholder farmers' use and perception of these agricultural mobile apps and
2. Identify the socio-economic characteristics affecting the use of agricultural mobile apps by smallholder farmers in Myanmar.

6.1.3 Research hypothesis

In this study, we hypothesized that:

1. Socio-economic factors are important for the use of agricultural mobile apps and
2. Different socio-economic factors may have a causal relationship with the use of agricultural mobile apps.

The hypotheses were anchored around the key research questions of the socio-economic characteristics of smallholder farmers in Myanmar and how they influence the use of agricultural mobile apps.

The paper is structured as follows. In Section 6.2 we describe the methods of the study including the study area, data collection process, empirical modelling used for measuring the determinants of agricultural mobile apps and the explanatory variables used in the model. Section 6.3 presents the results and discussion followed by conclusions and recommendations in Section 6.4 and implications of research in Section 6.5.

6.2 Methods

6.2.1 Study area

The study area was the southern margin of the Central Dry Zone and Upper Bago Region of central Myanmar. This study was part of a project (ACIAR, 2016) assessing soil and crop fertility management for cereal crops with objectives to study smallholder fertilizer decisions and investigate the use of decision support tools to improve household incomes and local food security of small-scale farmers and their families. Project field trial sites were established in the Townships of Tatkon, Zeyarthiri and Taungoo (Figure 25). The present study was focused on the population of smallholders in these Townships surrounding the trial sites.

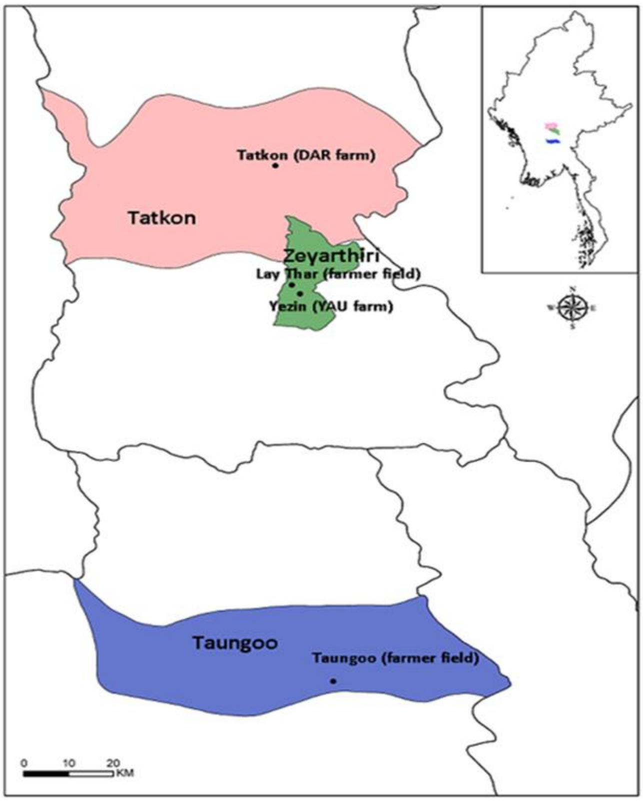

Figure 25. Study area, trial sites and Townships in central Myanmar

6.2.2 Data collection

A household survey was conducted by interviewing 600 farmers from May to July 2018 in the Townships of Tatkon, Zeyarthiri and Taungoo in the Central Dry Zone of Myanmar (Farquharson et al., 2019). A stratified systematic sampling technique (Cochran 1977) was used to randomly select the farmers across these Townships. Grids of 1000m x 1000m surrounding each trial site were overlaid within each Township. The purpose of the grid was to generate villages that would provide diverse contextual settings. Ten villages that fell within each grid and containing the highest population of farmers were selected from each township (total 30 villages). A ratio of 8:2 for male and female farmers were selected based on the male: female population ratio in the study area to investigate gender differences in access to mobile technology (Table 20).

Table 20. Sample size determination

	Tatkon	*Zeyarthiri*		*Taungoo*	*Total*
Township populations of farmers	14,879	7,399		12,536	34,814
		Male 5,832	Female 1,562		
Total farmers within the grid	4,300	3,261		2,388	9,949
Sample Size	258	196		146	600
Male sample size	208	149		112	469
Female sample size	50	47		34	131

Village farmer population lists were obtained from each Village Leader, who was consulted prior to the survey interviews. The first farmer to be interviewed was randomly selected to reduce the bias of household selection. If the farmer was not available at the time of the interview, or declined to participate, the next farmer on the list was selected. The selected farmers were contacted a day in advance and notified of the estimated time and place of the interview, which was either at the chief farmer's house or at Knowledge Transfer Centers. The criteria for respondent farmers included farmers who

- Were the head of the household or household member who led the farm work,
- Were actively cultivating land either as a landowner or land tenant and
- Expressed availability and willingness to participate in the survey.

A survey questionnaire was developed and structured to understand farmers' perceptions of agricultural mobile apps in aiding farm decision making and information sharing. Questions related to household demographics, farmland area, crop areas and types, information of farmers' access to mobile phones (smartphones), utilization and challenges. This was transcribed into the CommCare mobile data collection app (Dimagi 2017; Ziegler 2017). Four agricultural graduates from Yezin Agricultural University (YAU) were hired as casual workers. They were trained and given access to the questionnaire for data collection.

A pilot survey (Lancaster et al. 2004) was conducted to test the flow and format of the questionnaire. Information on mobile use, knowledge and decisions were collected. GPS coordinates were recorded allowing measurement of the distance from individual farmer fields to the nearest market. Distance to market through the local road network was determined using the 'Distance to Nearest Hub' network analysis function in QGIS 2.18 (http://www.qgis.org). Nominal centers of farmer field polygons were the source points and destinations were the locations of the respective local markets in each Township. Farmer fields and market locations were connected by a road layer shapefile obtained from OpenStreetMap (https://www.openstreetmap.org) which was verified and corrected with reference to the researcher's ground knowledge and Google Earth images prior to the network analysis.

6.2.3 Empirical modelling of factors affecting the adoption of agricultural mobile apps

Binary and Multinomial Choice Models have been used to measure the adoption of technologies among farming communities (Khan et al., 2020; Mittal et al., 2010; Rahman and Fadol, 2013). In this study, the Probit regression model (Greene, 2003) was employed to consider factors relating to adoption of agricultural mobile apps. The dependent variable was binary, taking on values of zero or one if the farmer had not or had adopted a mobile phone app (Aldrich and Nelson, 1984). Previous studies have used Probit models to distinguish the factors influencing the decisions to adopt new technology (Adesina, 1996; Makokha et al., 2001). The Probit model is a statistical probability model having two categories in the dependent variable and based on the cumulative normal probability distribution (Liao, 1994). Based on Hübler and Hartje (2016) and Ma et al (2018), the decision to access smartphones and use of agricultural mobile app was modelled using a random utility framework as specified in models explaining smartphones and mobile phone apps. In this study, we assigned a numerical value 1 if the farmer was a user of any of the agricultural mobile apps, otherwise a value 0 was assigned.

Let denote the difference between the utility from using an agricultural mobile app () and the utility from not using) such that an individual *i* will choose to use the mobile app if .

Since the utilities cannot be observed directly, they are expressed as a function of observable components in the latent variable model below.

=β+ with = 1 if , 0 otherwise,

where is dummy variable for app use (1 for users, 0 for non-users); β is a vector of parameters to be estimated; is a vector of exogenous explanatory variables; and is the random error term, which is assumed to be normally distributed with a zero mean.

6.2.3.1 Description of explanatory variables used in the model

Factors influencing the use and adoption of mobile phones for agricultural information dissemination have been widely studied (Aldosari et al., 2017; Khan et al., 2020; Obong et al., 2018). In the absence of significant studies directly looking into the factors affecting mobile apps, we used mobile phones as a proxy to use apps. Socio-economic factors such as age, level of education and income were found to be crucial in adopting mobile phones for farm information (Dissanayeke and Wanigasundera, 2017; Mittal et al., 2010). Farmers of different age groups use a mobile phone to share and access various types of agricultural information, but this trend is more prevalent among younger farmers, most of whom are more educated (Rahman and Fadol, 2013). Jain and Hundal (2007) reported that the age group for highest use of mobile phones was 20 - 40 years and Richardson et al. (2000) found that people under 30 years of age were able to access wider services and functions of mobile phones. Islam and Grönlund (2011) observed that people with no formal literacy were still able to perform basic operations with phones and gain access to mobile interfaces by using signs and symbols on the phone. Nyamba and Mlozi (2012) found that the education level of farmers had no influence on the use of mobile phones for communication of agricultural information. On the other hand, Hartje (2017) and Ma et al. (2018) argued that education level contributed to mobile phone use as some functions with mobile phones and apps require a certain level of education or literacy for effective and efficient utilization. Income level influenced usage rate and access to information (Kalba, 2008). Similarly, Cole and Fernando (2012) revealed a positive relation between the benefits of mobile applications with wealth and education level of farmers. Blumenstock and Eagle (2010) found that mobile phone users are considerably wealthier, better educated, and more predominantly male than the general population. Farmers producing perishable products such as banana in rural areas were found to benefit from the mobile phone expansion compared to farmers closer to markets (Muto and Yamano, 2009). Considering the literature (Hartje, 2017; Ma et al., 2018; Mittal et al., 2010), the availability of data and the context of the study, eight explanatory variables were selected for the current research (Table 21).

Table 21. Description of the explanatory variables in the analysis

Variables	Description	Definition
Dependent variable		
Use of agri-mobile apps	Dummy, 1=user, 0=non-user	The use of agricultural mobile apps by farmers in Myanmar
Explanatory variables		
Age	Continuous (Years)	Age of the respondent in years
Education	Continuous (Years)	Education of the respondent categorised as No formal education 0 Primary school 1 to 5 years Middle school 6 to 9 years High school 10 to 11 years Tertiary education 12 to 16 years Graduate 17 years or >
Gender	1=female, 0=male	Sex of the respondent; male or female
Crop income	Continuous (USD/season)	Total income received from cultivated crops per season in MMK[a] converted to USD
Off-farm income	Continuous (USD/month)	Total income received by the family per year from non-farm related activities in MMK[a] converted to USD
Number of crops	Continuous (Number)	Total number of crops grown by the respondent within a year
Degree of mechanization	Continuous (Number)	Sum of all types of machinery such as tractors, threshers, sprayers and water pumps at household level
Distance	Continuous (Km)	Distance from the individual farmers field to the nearest market measured in km

[a] MMK = Myanmar Kyats, we used the exchange rate of 1USD = 1300 MMK when the survey was carried out.

These variables were age, education, gender, wealth indicating variables (crop income, off-farm income, degree of mechanization, and number of crops) and distance of field to market. The dependent variable was assumed to be directly influenced by the independent variables, either positively or negatively. The *a priori* expectations of how each explanatory variable might influence the use of agricultural mobile apps are shown in Table 22.

Table 22. Expected signs of explanatory variables on use of agricultural mobile apps

Variables	**Sign (+/-)**	**Rationale**
Age	(-)	Older farmer less likely to use agricultural mobile apps
Education	(+)	Farmers with higher education levels more likely to use agricultural mobile apps
Gender	(+)	Men more likely to use agricultural mobile apps
Crop income	(+)	Farmer with higher crop income more likely to use agricultural mobile apps
Off-farm income	(±)	Farmers with higher off-farm income can more afford to use agricultural mobile apps Alternatively, they might not have time to utilise with 2 or more jobs
Number of crops	(±)	Farmers cultivating more crops more likely to use agricultural mobile apps if they require more information. Alternatively, farmers specialising on a fewer crop likely to use more apps
Degree of mechanization	(+)	Farmers possessing mechanization more likely to use agricultural mobile apps
Distance	(-)	Farmers further away from market more likely to use the app as they have less opportunity for extension officer to visit and less access to information

6.3 Results and Discussions

6.3.1 Socio-demographic characteristics of respondents

The average values of the key variables used in the analysis are shown in Table 23. The mean age of farmers was 50 years which shows that most belonged to the middle and older aged groups. This was consistent with the findings from Harper et al. (2017), who reported the ageing of Myanmar's farmer population and raised concerns over decline in young farmers, availability of labor and the sustainability of farming with an older farming population. Most of the farmers had only primary level education, the mean period of schooling was five years.

Regarding income, average total crop income per season was USD 277 and average total off-farm income per month was USD 253. Off-farm activities include working for private or public firms, casual work, trading, transport business and owning a shop. The number of crops grown per household varied from a single crop up to a maximum of nine crops. With respect to mechanization, on average farmers owned two types of farming machinery such as sprayers and water pumps. Average distance from field to market was 11 kilometres.

Table 23. Respondent socio-demographic characteristics (n=600)

Variables	**Mean**	**SD**	**Minimum**	**Maximum**
Human capital indicators				
- Age (years)	50	13	18	86
- Education (years)	5	3	0	17
Wealth and income indicators				
- Crop income (USD/season)	277	289	0	2,215
- Off-farm income (USD/month)	253	639	0	3,195
- Number of crops	2	1	1	9
- Degree of mechanization	2	2	0	12
Access to market indicators				
- *Distance (km)*	11	5	2	21

6.3.2 Mobile phone ownership

Mobile phone ownership in the study area was high, 71% of farmers in the study area owned a mobile phone. Many farmers were also keeping up to date with technology, with 62% owning smartphones. Smartphones are defined here as mobile phones with internet access, as distinct from older (basic) mobile phones without internet access (Chang et al., 2009). However, the use of internet among the surveyed farmers remains relatively low at 38%. A higher proportion of male farmers were using mobile internet (41%) compared to female farmers (26%). The GSMA (2018) report also suggested that although there is an increase in the number of women owning mobile phones over the past few years, a significant gender gap remains in the usage of transformational services such as mobile internet. These results are given in Supporting Information Table A2. Among the farmers who use internet, 75% rated the internet connectivity as *"good"* in the study areas (Supporting Information Table A3).

6.3.3 Farmer perceptions on use of agricultural mobile apps for farm decision making

Farmer perceptions towards technology have a strong influence on adoption behavior (Meijer et al., 2015). Of the 600 farmers interviewed, only 22% were aware of agricultural mobile apps which could assist in farm decision making and 21% of farmers used them (Table 24). However, 73% of farmers responded that they are keen to follow the recommendations from mobile apps.

Table 24. Perceptions of farmers about agricultural mobile apps

	Question	**Response (%)**
All *(n=600)*	Awareness of mobile apps that can help farm decisions	22
	Use of agricultural mobile app	21
	Keen to follow the recommendations from mobile apps	73
Users *(n=123)*	Are the apps useful?	85
	Any issues with apps?	19
	Recommend to other farmers?	70
Non-user *(n=477)*	Want to start using?	60

Among the farmers already using agricultural mobile apps, 85% stated that the mobile apps were useful and 70% would highly recommend other farmers to use apps, as additional information is useful for farm decision making. One farmer mentioned that mobile phones are very handy to receive market information easily and he no longer needed to travel to market for price information. Aker (2008) found that mobile phones reduced price dispersion across markets and lowered the variation in intra-annual price. Another farmer reported the importance of weather apps in forecasting weather to improve decisions on cultivation, harvesting and other management practices. Among the farmers who have not used any agricultural mobile apps, 60% would like to use the apps if there is good internet connectivity.

A majority of farmers (54%) were familiar with information received through Facebook groups while the remainder were aware of mobile apps such as Green Way (10%), Ooredoo Site Pyo (13%), Golden Paddy (14%) and others (Htwet Toe, PP 36%) (Supporting

Information Table A4). Farmers considered "Facebook" as an agricultural mobile app where they can obtain agricultural information. Whitten-Woodring et al. (2020) reported that Facebook has the potential to influence decisions and has become a primary source of news in Myanmar. In Myanmar, Facebook is also used as a search engine and has become an essential app on every phone, with many people using it on a daily basis (Leong, 2017). The Myanma Awba Facebook Page has over 1.5M followers and has become an interactive platform for exchanging knowledge and sharing information among farmers and stakeholders. Meirmanova (2019) described the Green Way app as a game-changer among agricultural apps in Myanmar for providing various up-to-date information to farmers including weather and climate change, crop prices and fertilizer/pesticide advice.

Although most farmers stated that mobile apps are useful, the intensity of mobile apps usage varied among farmers. From the study, 56% of the farmers used apps once a month, 20% only once a week, 19% every day and the remaining 6% rarely used the app (Supporting Information Table A5). Farmers attitude towards mobile applications were also addressed using a five-point scale *(1=highly unfavorable, 5=highly favorable)* (Albaum, 1997; Boone and Boone, 2012). The overall attitude towards mobile apps in the study area was positive with 56% being favorable towards apps as a means of obtaining information to improve farm decision making.

6.3.4 Constraints to adopt agricultural mobile phone apps

Of those respondents not keen to use apps, the main constraints included not having access to smartphone and/or internet (63%), lack of digital knowledge (20%), not interested (10%), money (4%) and age (3%) (Supporting Information Table A6). The cost of internet connection in Myanmar is US$1 per GB, and the daily minimum wage is US$3.60. One farmer reported that "*mobile apps are only useful when the person knows how to use it otherwise it takes up extra space in the phone*". Farmers mentioned that training would be beneficial to effectively utilize the apps. Regarding issues in using the apps, lack of images, poor lighting when reading information on small screens especially in bright field conditions, and apps providing too many recommendations with the lack of site-specific information were mentioned by most farmers.

6.3.5 Determinants of agricultural mobile app use

A Probit model was tested to determine the factors associated with agricultural mobile app use. The estimated parameters and the marginal effects of the Probit model for app use are presented in Table 25 and more detail is provided in Supporting Information Tables A7 and A8. The marginal effects refers to the average individual (Leeper, 2018). The likelihood ratio test with the chi-square value of 118 with 8 degree of freedom and an associated p-value of less than 0.001 indicates the model is said to fit the data significantly better than the more restrictive intercept only model. The factors which were positively significant for farmers' use of agricultural mobile apps included education level and degree of mechanization, while farmers' age, number of crops and market distance were negatively significant (Table 25).

Table 25. Probit model results of factors affecting app use

Variables	**Coefficient**	**P >|z|**	**Marginal Effect**
Age	-5.773e-02	2.13e-12 ***	-1.9549e-02***
Education	1.159e-01	5.07e-05 ***	3.9242e-02 ***
Gender	2.635e-01	0.19366	8.5034e-02
Crop income	1.542e-08	0.43771	5.2199e-09
Off-farm income	3.890e-04	0.32005	1.3173e-04
Number of crops	-1.390e-01	0.03530 *	-4.7071e-02*
Degree of mechanization	1.084e-01	0.03791 *	3.6703e-02*
Market Distance	-2.965e-05	0.07114 *	-1.0041e-05*
Constant	1.462e+00	0.00389 **	
Summary statistics			
Chi square value X^2	118		
d.f.	8		
p-value	1.040446e-21		
Observations	372		

* statistically significant at 5%, ** statistically significant at 1%, *** statistically significant at 0.1%

Age: Age is an important factor affecting behaviour and decision making. The age of a farmer represents knowledge and experience in the field (Harper et al., 2017). From these results, farmer age was highly significant in relation to the use of agricultural mobile apps. The negative value of the coefficient indicates a decrease in use of agricultural mobile apps with the increase in age of the farmer. The marginal effect suggests that older farmers have a lesser tendency (1.9% times) of using agricultural mobile apps compared to younger farmers (Ma et al., 2018). Roy et al. (2018) suggested that older farmers tend to follow traditional knowledge and beliefs and do not rely on new ICTs. These results are consistent with Khan et al. (2020) and Rose et al. (2016) who also found a negative relationship between age and use of mobile tools.

Education: Many studies have reported that the education level of farmers plays an important role in the use of ICTs such as mobile phones (Hartje, 2017; Ma et al., 2018). The positive and statistically significant coefficient of the education variable was expected and this study indicates that marginally better educated farmers are 3.9% times more likely to use agricultural mobile apps. Islam and Grönlund (2011) observed that people with no formal literacy are still able to perform basic operations with phones such as calling, whereas in the case of agricultural mobile apps, where more functions are available, higher literacy is necessary. From this result, it can be concluded that better-educated individuals may be more knowledgeable and better skilled and, hence, more likely to adopt this type of ICT.

Gender: There was no significance difference in gender on the use of agricultural mobile apps, as the mobile phone use among female farmers has been increasing. The stereotypical view of women having a negative attitude towards technology use has changed across time (Buccheri et al., 2011). Sainz et al. (2016) also stated that males did not show a more positive attitude towards technology use than females.

Crop income and off-farm income: There were no significant effects for agricultural mobile app used associated with crop income or off-farm income. This is mainly because farmers already own a phone and most agricultural mobile apps are free to download. In Myanmar, "Zapya" app which is a free peer-to-peer file sharing app via Bluetooth, is widely used for app distribution and installation (Said et al., 2018). However, it can be argued some agricultural mobile apps require the use of internet and affordability can be an issue.

Number of crops: The negative significance for number of crops indicates that more specialised farmers tend to use agricultural mobile apps. Apps focusing on a single crop that are simple and easy to use are known to attract more users (Mir and Quadri, 2009; Rose et al., 2016).

Hence it is better for apps to start simple and focussed by specialising in fewer crops than to commence with complex services providing recommendations for many crops.

Degree of mechanization: The degree of mechanization has a positive and significant effect suggesting that better mechanized farmers are 3.6% more likely to use agricultural mobile apps.

Distance: Market distance was found to be negatively significant suggesting that farmers further away from markets are less likely to use apps. The distance to the market can also be regarded as a proxy for the strength of internet connection as broadband coverage is mainly available in public locations.

6.4 Conclusions and Recommendations

Access to quick and reliable information will help improve farm decisions. Agricultural mobile apps can convey necessary information to farmers in a timely manner. However, low uptake by farmers has been a challenge. In our study, we found that only 21% of the farmers were currently using agricultural mobile apps with a majority (56%) only opening them once a month. The main reasons for such low use of mobile apps for farm decision making were lack of awareness and knowledge, along with the high cost of internet. However, farmers are optimistic about agricultural mobile apps with over 70% of the farmers willing to use them. The positive attitude towards agricultural mobile apps and negative usage level of most respondents in the study seems a challenge in introducing mobile-based agricultural support tools.

On the other hand, we found that a majority of surveyed farmers (54%) were familiar with information received through Facebook groups. Since Facebook has established trust and the majority of the smallholder farmers are using it, incorporating useful information and functions from an agricultural mobile app to a Facebook Page would have a more useful and sustainable impact, at the same time eliminating the issues such as lack of awareness, lack of use, and long-term servicing and sustainability.

Specific policies are possible to improve accessibility and affordability of internet regardless of socio-economic status and expanding broadband coverage with targeted public sector support. Mobile operators in Myanmar have rolled out packages such as "Myanmar's Cheapest Facebook Pack", "Unlimited Facebook", "Social Pack Promo" which provide access to apps such as Facebook at a relatively low cost. Hence, delivering agricultural information through Facebook can also solve the constraint of expensive internet. In addition, a Facebook app would be available in local language and therefore reach a greater number of people.

In order to analyze the socioeconomic factors, we employed the binary Probit model to a large set of survey data. Our empirical results demonstrated that socio-economic factors such as age (negatively), education (positively), degree of mechanization (positively), number of crops (negatively) and market distance (negatively) were found to affect the use of agricultural mobile apps. Hence, it is suggested that when introducing mobile-based agricultural support tools, focus should be given to younger, educated farmers with more specialized crops as early adopters. Education appears to be a barrier to large scale adoption of apps by farmers as most of these farmers only have primary level education. There is a higher proportion of female farmers without any formal education compared to males. Literacy intervention programs and training to ensure that more women farmers are literate and to provide digital skills for adapting and utilizing ICT remain important. Studies on farm typology can be useful to further distinguish specific farmer groups to target training and participation in the use as such group will have better possibilities and potential for adoption than others.

However, these empirical results reported should be considered in the light of some limitations in the explanatory variables used and including mobile phone use-related attributes (skills of using mobile phone, digital literacy, duration of phone ownership) would be useful. Moreover, the scope of the study is limited to smallholder farmers and the results may not apply to large scale commercial farmers.

6.5 Implications for research

This study provides valuable context for discussion of important factors needing to be considered in developing and scaling up agricultural mobile apps to assist farmers with day-to-day farm decisions. This information is important as many agricultural mobile apps have been developed to date and are continuing to be developed for decision support to farmers, when these apps are not widely being utilized by farmers. The study suggests although the current usage remains low, farmers in Myanmar have a positive attitude towards agricultural mobile apps to obtain information. When introducing agricultural mobile apps younger, more educated farmers growing more specialized crops should be targeted. Having reviewed the existing agricultural mobile apps and the information system platforms in Myanmar, we found that Facebook was widely used by farmers. Incorporating features and functions into existing social media platform such as Facebook should be promoted and encouraged as it may have a more useful and sustainable impact compared to setting up new mobile apps and DSTs which may not last long without a 3rd party input to maintain the app. We expect that our study results will benefit international, private and public sector organizations in developing and scaling up agricultural mobile apps to be effectively utilized by farmers.

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Supporting Information

Table A1: Summary of agricultural mobile apps available in Myanmar

Features	Agricultural Mobile Apps in Myanmar				
	Green Way	**Ooredoo Site Pyo**	**Golden Paddy**	**Htwet Toe**	**Plant Protection**
Mission	To share alternative agricultural techniques with farmers to help them improve their agricultural outputs and income levels	To improve farmers' lives by providing information that improves yields	To digitally empower smallholder farmers around the world	To support agriculture knowledge to get more profit for farmers in Myanmar	To promote the effective and safe usage of pesticides on agricultural products
Provider/ Developer	Greenovator	Ooredoo Myanmar	Impact Terra	Village Link	DoA Myanmar
Cost of App	Free	Free	Free	Free	Free
Mobile Compatibility	Android 4.2 and up	Android 4.0.1 and up	Android 4.1 and up	Android 4.1 and up	Android 4.0 and up
Size	20 MB	6.48 MB	12 MB	14 MB	N/A
System Requirements	Internet connection	Internet connection & Ooredoo SIM	Available offline	Internet connection	Available offline
Target users	Farmers, Extension officer	Farmers	Farmers, Stakeholders	Farmers	Farmers, Extension officer
Launch year	2016	Mar 2016	2016	Dec 2017	2017
Current users	103,461	150,000	N/A	N/A	N/A
Partners/Funding	Multiple projects	GSMA mAgri Program (UK aid)	Smart Agriculture Myanmar (SAM) (Dutch govt.)	Geodata for Agriculture and Water (G4AW) program (Dutch govt.)	Commonwealth Agricultural Bureau (UK aid)
Highlight of the app	Chat feature	Interactive voice response feature	*Link farmers to financial institutions and markets*	Live chat function where farmers can upload photos and get advice	Specific for pest and disease management
Reference	www.en.greenwaymyanmar.org/	GSMA (2017)	www.impactterra.com/golden-paddy	www.htwettoe.com/	(www.ppdmyanmar.org/)

Table A2. Use of internet and devices

	Male (n=469) %	*Female (n=131) %*	*Total (n=600) %*
Mobile ownership	72	66	71
Smartphone ownership	63	60	62
Internet use	41	26	38

Table A3. Farmers rating on the strength of the internet in the study area (n=225)

Internet Strength	**%**
Extremely Good	0%
Good	75%
Average	18%
Poor	7%
Extremely Poor	0%

Table A4: Awareness of agricultural mobile apps by Myanmar farmers (n=600)

Agricultural Mobile Application	**%**
Facebook	54%
Green Way	10%
Ooredoo Site Pyo	13%
Golden Paddy	14%
Others (Htwet Toe, PP)	36%

Table A5. The intensity of the mobile apps usage (n=123)

Intensity	**%**
Every day	19%
Once a week	20%
Once a month	56%
Rarely use	6%

Table A6. Constraints to adopt agricultural mobile apps

Constraints	**%**
Lack of access to smartphone and/or internet	63
Lack of digital knowledge	20
Lack of interest	10
Cost	4
Age	3

Table A7. Probit Analysis for factors affecting agricultural mobile app use

Variables	*Coefficient*	*Std. Err.*	*z*	*P >|z|*
Age	-5.773e-02	8.218e-03	-7.025	2.13e-12 ***
Gender	2.635e-01	2.027e-01	1.300	0.19366
Education	1.159e-01	2.860e-02	4.053	5.07e-05 ***
Off-farm income	3.890e-04	3.912e-04	0.994	0.32005
Degree of mechanization	1.084e-01	5.222e-02	2.076	0.03791 *
Number of crops	-1.390e-01	6.604e-02	-2.105	0.03530 *
Crop income	1.542e-08	1.986e-08	0.776	0.43771
Market Distance	-2.965e-05	1.643e-05	-1.805	0.07114.

* statistically significant at 5%, ** statistically significant at 1%, *** statistically significant at 0.1%

Table A8. Marginal effect of app use

Variables	*Marginal Effect*	*Std. Err.*	*z*	*P >|z|*
Age	-1.9549e-02	2.7163e-03	-7.1971	6.151e-13 ***
Gender	8.5034e-02	6.1852e-02	1.3748	0.16920
Education	3.9242e-02	9.7506e-03	4.0246	5.707e-05 ***
Off-farm income	1.3173e-04	1.3240e-04	0.9949	0.31978
Degree of mechanization	3.6703e-02	1.7631e-02	2.0818	0.03736 *
Number of crops	-4.7071e-02	2.2345e-02	-2.1066	0.03515 *
Crop income	5.2199e-09	6.7226e-09	0.7765	0.43747
Market distance	-1.0041e-05	5.5577e-06	-1.8067	0.07082 *

* statistically significant at 5%, ** statistically significant at 1%, *** statistically significant at 0.1%

Chapter 7

Journal Paper 3

Farming system typologies and participatory research for decision support in Myanmar

This chapter has been submitted to *Agriculture* and is currently under review.

Thar, S. P., Ramilan, T., Farquharson, R. J., and Chen, D. (2021). Farming system typologies and participatory research for decision support in Myanmar. *Agriculture* (Submitted).

Abstract

CONTEXT: Decision Support Tools in agriculture have suffered from low levels of use, apparently due to limited acceptability by end users. Many of these tools appear to have been developed from a scientist-based perspective, but recent efforts have been made to include end-user participation in development. Previous studies have utilized various participatory approaches with farmers but have not accounted for complexity of heterogeneous smallholder farming systems. Farm typology analysis has facilitated transfer and adoption of appropriate technologies to target groups of farmers. Recognizing heterogeneity in farm systems can help in designing and deploying Decision Support Tools to address farmer needs.

OBJECTIVE: The study aims to develop farm household typologies for a population of smallholder farmers in central Myanmar and introduce the concept of a DST to farmers to explore whether the farmers in different farm types generally exhibit different opinions towards digital tools.

METHODS: This study utilized typology analysis, applied to a survey dataset, to identify different farm system types and used qualitative participatory research to assess potential deployment of decision support tools for fertilizer management.

RESULTS AND CONCLUSIONS: Six types of farm systems were identified with distinct characteristics in the study area of central Myanmar. Participatory research through focus group discussions validated the farm typologies and provided evidence that farmers belonging to one type considered that Decision Support Tools could be useful in gaining more information and knowledge. Farmers interested in the technology indicated that discussion groups are better tools for learning and preferred a learning-based approach rather than a prescriptive tool. Farmers preferred video clips and infographics integrated into existing familiar digital platforms such as social media and available agri apps.

SIGNIFICANCE: This study contributes by identifying heterogeneity among farmers in a statically robust manner and developing a deeper understanding of fertilizer decisions as well as knowledge and intentions related to Decision Support Tools/Apps via the follow-up Focus Group Discussions. It has generated valuable information about farmer types and serves as a starting point for developing a framework for discussion support systems which may better relate to the needs of farmers.

Keywords: decision support tools; typology; participatory research; focus group discussion; smallholder; Myanmar

Graphical Abstract

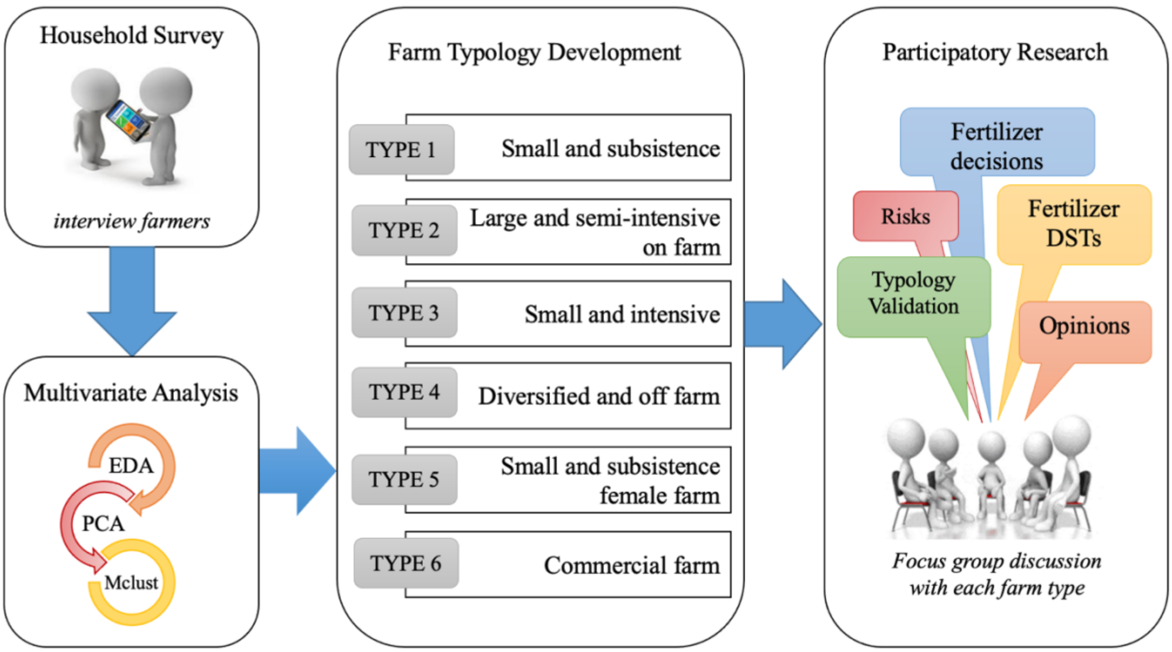

Figure 26. Farming system typologies and participatory research for decision support in Myanmar

7.1 Introduction

Myanmar is a country rich in natural resources but, in general, its agricultural productivity has underperformed compared to other countries in Asia (Findlay et al., 2015). Reports have highlighted that uncertainty in fertilizer decisions is a key factor contributing to the underperformance (Gregory et al., 2014; Herridge et al., 2019; IFDC, 2015; Stuart et al., 2016). In Myanmar most fertilizer decisions are based on visual field observations and advice from other village farmers (LIFT, 2015). The agriculture extension services are under resourced (Haggblade et al., 2013) and practice a 'traditional extension approach' focusing on individual contact with 'progressive farmers' who are generally resourceful and easiest to reach, leaving a majority of farmers neglected (Oo and Ando, 2012; Win et al., 2018). Therefore, it is important to improve information access by smallholder farmers to enable more effective decision making.

The focus on digital technology has been increasing, especially in developing countries such as Myanmar, where 80% of the population now own a mobile phone (Telenor, 2018). This provides an opportunity for smallholder farmers to use mobile phones in farm-level decision making. Thar et al. (2020) found that farmers in Myanmar were optimistic and positive towards agricultural mobile apps although there are many constraints to adoption. Decision Support Tools (DSTs) are electronic-based information technologies which can reduce uncertainty in farmer decision making (Shim et al., 2002). The use of mobile device-based DSTs in agriculture can help farmers access knowledge and information in a timely manner.

DSTs have been widely developed and are readily available in the field of agriculture (Paustian and Theuvsen, 2017). They are tools designed to provide solutions for crop preparation and planning, and sowing and harvesting, as well as providing recommendations for different management practices (e.g. seed rates, irrigation, pest and disease remedies, fertilizer application) according to seasonal climate variability (e.g. rainfall and temperature) (Churi, 2013). Despite these potential uses and benefits, there is limited evidence of the acceptance of these tools by farmers (Alvarez and Nuthall, 2006; Kerr, 2004; McCown, 2002; Shtienberg, 2013). The challenges and issues for successful uptake by farmers include limited user participation and involvement in the design and implementation of the tool (McCown, 2002; Prost et al., 2012), lack of trust in the information and recommendation provided (He et al., 2016; Rose et al., 2016), tools not being simple and easy to use, and requiring advanced digital skills (Armstrong et al., 2003; Nguyen et al., 2007). Socioeconomic (Fixen, 2005) and behavioral factors (Batte et al., 1990) are also important.

Applied research has been conducted to address these challenges and improve the DSTs, including use of participatory approaches and consideration of user-centered aspects for successful delivery of DSTs (Antle et al., 2017; Carberry et al., 2004; Jakku and Thorburn, 2010; Lacoste and Powles, 2016; Parker and Sinclair, 2001; Smith et al., 2017; Thorburn et al., 2011; Valls-Donderis et al., 2014; Van Meensel, 2012). Participatory approaches have been successful in gaining interest from farmers and policy makers with promising results for adoption. Yield Prophet (Hochman et al., 2009; Hunt et al., 2006) demonstrates farmer participation in using a systems approach for decision making as it integrates the FARMSCAPE (Farmers', Advisers', Researchers', Monitoring, Simulation, Communication And Performance Evaluation) program (Carberry et al., 2002; Hochman et al., 2000) and is one of few tools still continuing today (Keating and Thorburn, 2018; Robertson et al., 2016; Robertson et al., 2015). Hochman and Lilley (2020) argued that while some farmers have continued to use Yield Prophet for many years, most farmers use it only for a shorter period. The long-term sustainable adoption of DSTs continues to be doubtful.

There are many examples of technologies that have not been utilized by smallholder farmers (Chatterjee et al., 2015) as they fail to recognize the complex heterogeneity among farming populations (Emtage and Suh, 2005). Smallholder farming systems are heterogeneous because of differences in socio-economic and agro-ecological characteristics (Asfaw and Admassie, 2004; Lesson et al., 1999; Mahapatra and Mitchell, 2011). It is important to consider the heterogeneity of the farmers so that any DST can be designed to reflect farmer needs and target appropriate end users.

Farm typology analysis has been used to classify farmers with similar circumstances based on selected criteria and has been helpful in targeting technological interventions for rapid transfer and adoption (Alvarez and Nuthall, 2006). Many studies have addressed the importance of farm household typology influencing farm technology adoption (Bidogeza et al., 2009), nutrient management technologies (Chikowo et al., 2014; Daxini et al., 2019; Tittonell et al., 2006), resource use efficiency (Zingore et al., 2007), integrated pest management (Leeson et al., 1999), and climate smart agricultural practices (Lopez-Ridaura et al., 2018; Makate et al., 2018).

Farm typology studies are useful for understanding factors explaining the adoption and/or rejection of new technologies (Kostrowicki, 1977). From a practical point of view, identifying the reasons for farmer adoption and/or rejection of new DSTs is important for the agricultural society, policy makers and related economic sectors. In particular, the typology of farmers, along with their opinions on DSTs, can provide useful policy insights on whether and how these tools can contribute to diffusion of innovations and rural development.

This study focuses on the types of smallholder farmers and their preference towards information access in Myanmar. We used typology analysis, applied to a survey dataset, to identify different farm system types and used qualitative participatory research to assess potential deployment of decision support tools for fertilizer management. Previous studies have utilized various participatory approaches but have not accounted for complexity of heterogeneous smallholder farming systems. The findings from this study may help developers of tools for decision support.
The research aimed to:

- develop farm household typologies for a population of smallholder farmers in central Myanmar, and

- introduce the concept of a DST to farmers and explore whether farm types generally exhibit different opinions towards digital tools.

7.2 Method

A structured questionnaire-based survey was conducted using the CommCare® mobile data collection platform to collect detailed information from 600 farm households. A multivariate analysis developed typologies of farm types to conduct Focus Group Discussions (FGDs) to investigate more diverse and in-depth views and allow comparison between the farm types. Subsequently, Focus Group Discussions (FGDs) were conducted with members from each farm type. The objectives of the FGDs were to validate the farm typology, explore how farmers in each farm type make fertilizer decisions for cereal crops, introduce the concept of a mobile based DST, and obtain opinions about using such tools in fertilizer decision making. We developed a deeper understanding of the heterogeneity of farmer preferences to identify potential early adopters of a mobile-based DST. Figure 27 illustrates the analytical framework of the study.

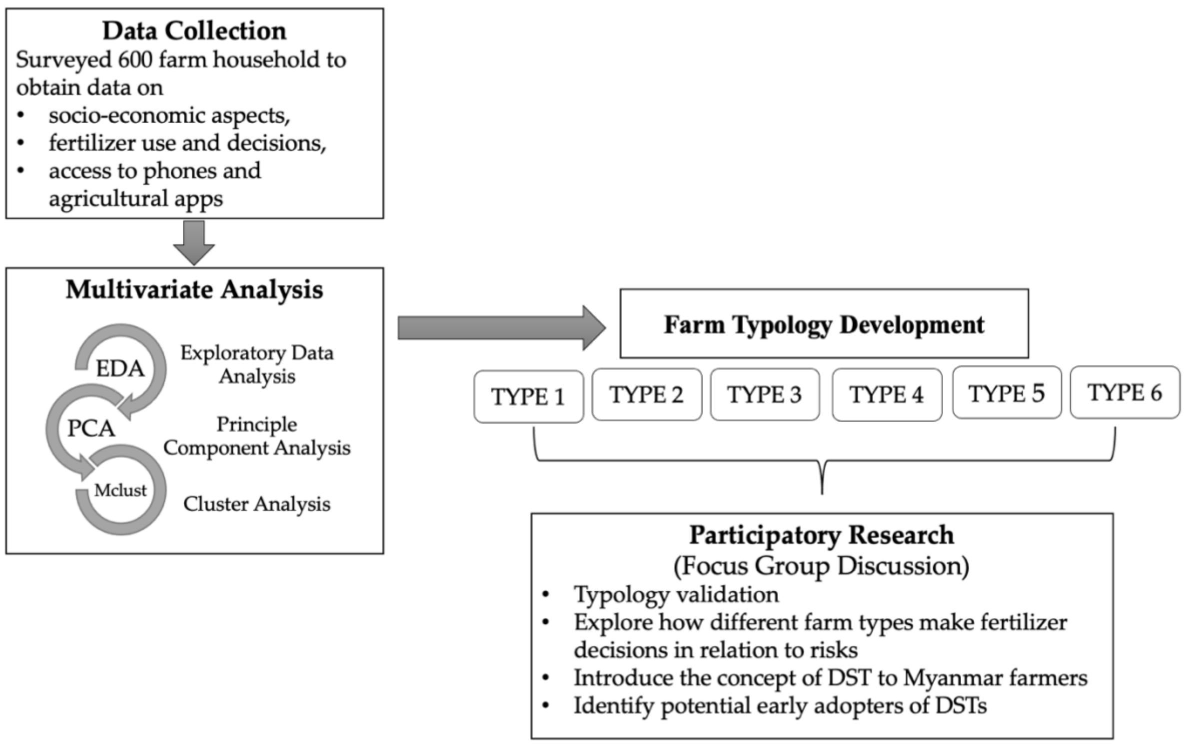

Figure 27. Analytical framework of the study

7.2.1 Study area and survey

The study was undertaken in three townships in central Myanmar: Tatkon, Zeyarthiri and Taungoo (Figure 28). Six hundred farmers were personally interviewed with a structured questionnaire using the CommCare® mobile data collection app (Flaming et al., 2016) in May to June 2018 (Farquharson et al., 2019). A stratified systematic sampling technique (Cochran, 1977; Levy and Lemeshow, 2013) was used to randomly select the farmers. In general, the survey questionnaire was structured to understand farmer's fertilizer use and decisions. The dataset provided information on farm household demographics, farmland and crops, inputs for farmer fertilizer and water use, and factors influencing decisions on fertilizer, outputs, and other sources of income. Other information collected related to farmers access to mobile phones (smartphones) and the use of agricultural mobile apps for farm decision making. In total, the dataset encompassed 410 variables.

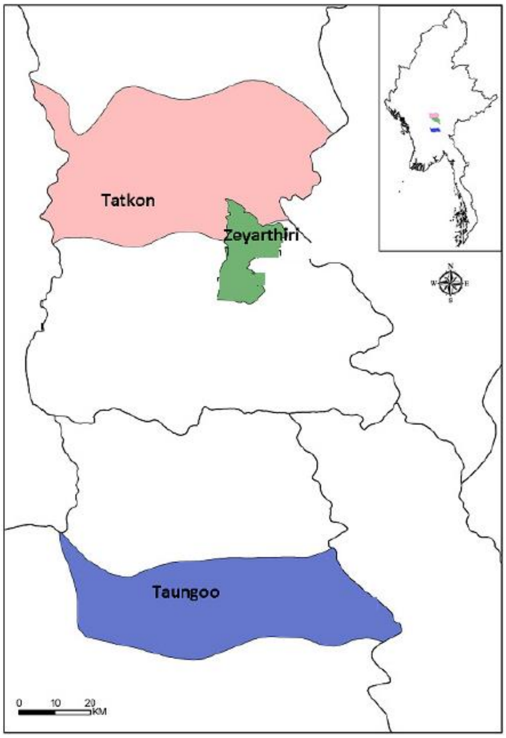

Figure 28. Study area in Myanmar

7.2.2 Typology construction

The typology approach has been used in studies to characterize farming systems (Bidogeza et al., 2009; Jezeer et al., 2018; Lopez-Ridaura et al., 2018). Principal component analysis (PCA) and farm clustering or cluster analysis (CA) were consecutively conducted to construct farm typologies (Gorton et al., 2008; Kobrich et al., 2003). PCA was used for data reduction via linear transformation of a large set of correlated variables into an uncorrelated set of components. Information from the original set of variables was preserved in this transformation. Principal components (PCs) were selected based on scree plot and cumulative variance explained by PCs (Field et al., 2012). The variables were identified through exploratory data analysis (EDA) and carefully selected since PCA is highly sensitive to outliers (Alvarez et al., 2014). To ensure robustness, variables used in the PCA were checked for outliers. Box plots were used to detect outliers before PCA analysis. One household was eliminated from the sample; hence, a total of 599 respondents were subjected to Kaiser Mayer-Olkin (KMO) and Bartlett's sphericity test to check data credibility for PCA (Field et al., 2012). Variables related to both socio-economic backgrounds and the use of fertilizers (17 variables) were used for the PCA (Table 1). Orthogonal rotation (varimax method) was used to group the study variables (Tittonell et al., 2010). All PCs exceeding an eigenvalue of 1 were initially retained for multivariate statistical analysis. These non-related PCs were used as inputs for the CA. This allows the number of variables to be decreased while retaining the information of value in the dataset. The CA was undertaken using model-based clustering with the 'mclust' algorithm (Scrucca et al., 2016). An optimal number of clusters was identified based on the Bayesian Information Criterion (BIC) (Fraley and Raftery, 2002; Fraley et al., 2012). Statistical analyses were performed with R (version 4.0.2) (R Core Team, 2020), using psych' (Revelle, 2020) and the 'mclust' packages (Scrucca et al., 2016). The identified farm types were then used for the focus group discussions (FGDs).

7.2.3 Procedure for FGDs

The focus group method (Krueger, 1988) is a participatory research approach, used to collect qualitative data (Cornwall and Jewkes, 1995). As the purpose of the study was to introduce the concept of a DST and explore farmers opinions towards digital tools to understand the best ways to support farmers upskilling and reskilling in the digital area, FGDs were adopted as an appropriate method to fully engage with farmers. FGDs are designed to obtain participant perceptions on a well-defined area of interest and are a valuable way to obtain a range of perceptions, feelings and opinions from interviewed groups of people (Yin, 2015).

In FGDs, opinions of individual participants are converted to a more or less shared group opinion (Kraaijvanger et al., 2016). In this study, six FGD workshops were conducted, one for each of the farmer types derived from the typology analysis. This was undertaken because farmer groups of similar types face similar constraints and may generate similar management strategies. But individual farmer characteristics, decisions, values, culture, background or personal goals will remain different and the study can account for the observed individual differences (Alvarez, 2018). This approach enables investigation of more diverse views and allows comparison of results between groups.

There were 34 participants in the six different farm types. These were a subset of randomly selected farmers from the original household survey. The number of participants in each group varied from four to eight. Farmers were invited to the group discussions with the help of the local agricultural extension officers. The FGDs were conducted by personal interview and farmers were given sticky notes on which to write their answers. Farmers who needed assistance with writing were helped. Most farmers were able to write. The discussions were planned based on the 3 main topics:

1. Typology Validation
2. Fertilizer Decisions/ Risks, and
3. Decision Support Tools/Apps.

Focus group responses were translated from Burmese to English and analyzed in NVivo Qualitative data analysis software (version 12.3.0) (Bazeley and Jackson, 2013).

7.3 Results and Discussions

7.3.1 Typology identification

The Kaiser-Meyer-Olkin (KMO) criterion confirmed that the PCA analysis is appropriate for the sample. The value of KMO for the analysis is 0.7, which is regarded as acceptable and all KMO values for individual variables were equal or greater than 0.54, which is above the threshold limit of 0.50 (Field et al., 2012). Bartlett's test of sphericity hypothesizes that the original correlation matrix is an identity matrix. We rejected the null hypothesis at the 5% level (p-value = $0 < 0.05$) with a Chi-square value of 9391, indicating that the strength of the relationship among the variables was strong and appropriate for factor analysis. Further the determinant of the matrix has a value of 0.00006, which is greater than the critical value

0.00001, which also rejects multicollinearity among variables. Based on the screen plot and cumulative variance of 70 percent, seventeen PCs were used for CA. The variables used for PCA analysis are listed in the Table 26.

Table 26. List of variables used in PCA

Variables (unit)	**Mean**	**SD**	**Description**
Gender	1.2	0.4	Sex of the respondent; 1 = male, 2 = female
Age (year)	50	13	Age of the respondent
Education (year)	5	3	Education of the respondent categorized as 0 = no formal education, 1–5 years = primary school, 6–9 years = middle school, 10–11 years = high school, 12 years or > = tertiary education
Farming experience (year)	27	13	Total number of years working on the farm
Household Size (number)	5	2	Total number of people living in the same household
Number of crops (number)	2	1	Total number of crops grown by the respondent within a year
Total livestock unit (number)	2	3	Total number of livestock raised on the farm
Degree of mechanization (number)	2	2	Sum of all types of machinery such as tractors, threshers, sprayers, and water pumps at household level
Total land ownership (ha)	2	3	Total area of land owned by the respondent in hectares
Sown area (ha)	1.6	1.5	Area of land under cultivation by the respondent in hectares
Crop income (USD/season)	277	289	Total income received from cultivated crops per season in MMK[a] converted to USD
Cereal Intensity (number)	0.7	0.3	The degree of cereal crops grown
Off-farm Income (USD/month)	253	639	Total income received by the family per year from non-farm related activities in MMK[a] converted to USD
Irrigated area (%)	10	20	The percentage of land area under irrigation in hectares
Marketing mode (indices)	2	1.4	Means of selling the produce; 1 = buyer comes to farm, 2 = takes to market, 3 = both
Urea cash or credit (indices)	1.7	1.1	Means of buying urea fertilizer; 1 = cash, 2 = credit, 3 = both
Average N use (kg/ha)	58	37	The average amount of N used

[a] MMK = Myanmar Kyats, we used the exchange rate of 1USD = 1300 MMK when the survey was carried out

Following the methods explained above, six types of farm systems were identified. This selection was based on BIC statistics generated from model-based clustering VVV (ellipsoidal, varying volume, shape and orientation) model (Fraley and Raftery, 2002). The selected six clusters showed the highest BIC value. The farm types were named after key livelihood assets and activities (Table 27). Details of the characteristics of the farm types are in Table 28.

Table 27. Name of farm types and their share in the sample

Name of farm typologies based on their key livelihood assets and activities	Assigned code	Share in the sample, N (%)
Small and subsistence	Farm Type 1	113 (19%)
Large and semi-intensive on farm	Farm Type 2	125 (21%)
Small and intensive	Farm Type 3	191 (32%)
Diversified and off farm	Farm Type 4	102 (17%)
Small and subsistence female farm	Farm Type 5	50 (8%)
Commercial farm	Farm Type 6	18 (3%)

Table 28. Characterization of identified farm types

Variables (unit)	Farm types					
	1	2	3	4	5	6
Age (year)	46	40	52	51	51	49
Education (year)	6	7	5	6	3	5
Farming experience (year)	24	27	30	28	20	26
Household Size (number)	4	4	5	6	4	6
Number of crops (number)	2	2	3	4	3	5
Total livestock unit (number)	0	2	2	1	1	7
Degree of mechanization (number)	2	2	2	2	1	4
Total land ownership (ha)	5	12	4	8	4	23
Sown area (ha)	2	6	4	4	2	15
Crop income (USD/season)	127	433	246	274	133	907
Cereal Intensity (number)	0.5	0.7	0.7	0.7	0.5	0.7
Off-farm Income (USD/month)	35	10	42	289	71	327
Irrigated area (%)	0	15	0	10	0	30
Marketing mode (indices)	3	3	2	2.6	3	3
Urea cash or credit (indices)	1.2	2	1.5	1.8	1.6	1.3
Average N use (kg/ha)	45	60	66	65	47	41

We developed a deeper understanding on the heterogeneity of farmer preferences to identify potential early adopters of a mobile-based DST.

Farm Type 1 (Small and subsistence) comprised 19% of the surveyed farm households. It was male dominated, with less than 1% female farmers in the group. This farm type comprised farmers having small land holdings, middle school education with low crop diversification, and cultivating on average two crops per year. This cluster was characterized by moderate crop income, low off-farm income and no livestock ownership. These households, on average, secured most of their income from crops.

Farm Type 2 (Large and semi-intensive, on farm) comprised 21% of the surveyed households with equal numbers of male and female farmers in the group. These farmers had relatively large land holdings, middle-school education, low resource endowments of livestock and machinery, and cultivated two crops per year. Farmers relied on-farm income and did not earn any income from off-farm work.

Farm Type 3 (Small and intensive) comprised 32% of the surveyed farm households with only 2% female farmers. Farmers in this type were very experienced with an average of 30 years farming history. This cluster was characterized by smaller areas of land holdings, primary school education levels, low resource endowments (livestock/machinery), and cultivated three or more crops per year. The cluster members earned low crop income and low off-farm income.

Farm Type 4 (Diversified and off farm) comprised 17% of the surveyed farm households with a quarter of members being female. The farm type consisted of farmers having moderate-sized land holdings, middle school education, low livestock ownership, moderate ownership of machinery, and cultivated four or more crops per year. The farmers belonging to this cluster had high off-farm income to offset their low crop income.

Farm Type 5 (Small and subsistence female farm) comprised 8% of the surveyed farm households and were all female farmers. They possessed small land holdings, primary school levels of education, low resource endorsements (livestock/machinery), and cultivated three or more crops per year. Female farmers had less farming experience. They obtained moderate income from crops but secured substantial proportion of off-farm income from sewing, working as street vendors, or operating small shops.

Farm Type 6 (Commercial farm) represented the highly resourced farmers and comprised only 3% of the surveyed farm households. The farmers belonging to this farm type were male with very large land holdings, middle school education and high resource endowments. They have emerged as integrated farms with high crop diversification to generate higher income with minimal risks. These farmers are diversified, based on animal husbandry (high livestock ownership) and high mechanization, with high off-farm income.

7.3.2 Typology validation

To verify whether the model-generated typologies resemble reality, validation was undertaken by discussion with an expert group of extension officers, followed by FGDs with members from each of the farm types. Common indicators (e.g. landholding, livestock ownership, on/off-farm income, etc.) for each farm type were identified by discussing with expert group of local extension officers based on Haileslassie et al. (2016). Using these identified indicators, a qualitative comparison (low, high) between the different typologies was obtained for farmers from the focus group of each farm type. And this was confirmed by local experts. A comparison of the six identified farm types in terms of key indicators is in Table 29. These results were found to resemble and match the model-generated farm types.

Table 29. Comparison of the six identified farm types to validate the typology

Indicators	Farm types					
	1	2	3	4	5	6
Land holding	Small	Large	Small	Moderate	Small	Very Large
Livestock ownership	Low	Moderate	Low	High	Low	High
Crop diversification	Low	Moderate	Moderate	High	Moderate	Very High
Crop income	Low	High	Moderate	Moderate	Low	Very High
Off-farm income	No	No	Low	High	Moderate	High
Gender	Male dominant	Mixed	Male dominant	Mixed	Female	Male

7.3.3 Fertilizer decisions/ risks

Once the model-generated farm system types were validated, farmers were asked if they apply any fertilizer to monsoon rice and the amount of crop yield received. All participating farmers were using fertilizer. Farmer answers were placed on a graph, so farmers were able to see that they apply different rates and even if some applied the same rates, they receive different yields (Figure 29).

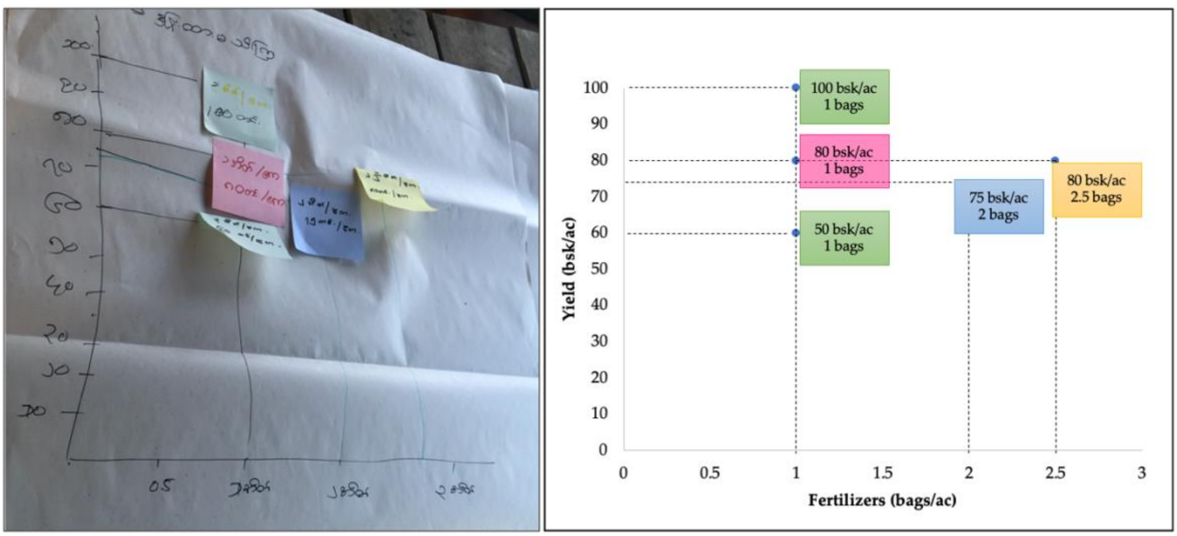

Figure 29. Photos of diagrams on flipchart used to help explain the relationship between yield and fertilizer

(Participation of farmers from Type 4). Bag = 50 kg bag of fertilizer, 1 bsk = 20.9 kg of rice.

The relationship between yield and fertilizer (N rates) were explained to farmers. Later, the reasons for different yields were asked to the farmers *"why they think they obtained less/ more yield?".* Nominated factors including crop variety, soil condition, weather, pest and disease infestation, water availability, input affordability as well as risk taking were described by the farmers.

Farmers mentioned the risky environments due to variability in climate and market prices. Farmer fertilizer decisions depended substantially on economic considerations as they must borrow money to buy fertilizer and pay interest and principal in repaying the loan. Farmers were asked about *"the important factors they consider in making these investment decisions"*. Interest rates and market prices were the two main factors emphasized by farmers in all farm types. Incentives to invest and opportunities to reduce risk were also mentioned. Most farmers in all farm types were borrowing money for farm operations (Table 5).

The degree of risk taking differed between farmers with some willing to take more risk than others (Harwood et al., 1999). Farmers attitudes to risk are often related to the financial ability of the farmer to accept a small gain or loss (Dillon, 2003). The attitudes of farmers can be categorized as: risk-averse, those who avoid taking risks; risk-takers, those who are open to riskier business options; and risk neutral, farmers who lie between the risk-averse and risk-taking (Kahan, 2008). Farmers were asked to rate their willingness to take risks in making decisions on a five-point scale (1= risk-averse and 5 = risk-takers). Overall, as indicated by the average scores in Table 5, commercial farmers in farm Type 6 were high risk takers (as they have other sources of income) and smallholders generally do not take risks because they don't have other assets or alternative income sources. Female smallholders were also less likely to take risks as they focus more on the possible negative outcomes. One farmer in farm Type 6 believed that the higher the investment, the more the profit, so he takes risks.

Discussions on trusting information sources showed the different sources in Table 30.

Table 30. Borrowing practices, attitudes to risk and sources of trusted information by different farm types

Criteria	Farm Types					
	1	2	3	4	5	6
Borrow money	Yes	Yes	Yes	Yes/No	Yes	Yes
Risk taking	High (4.5)	High (4.2)	Average (3)	Low (2.5)	Low (1.4)	Very High (5)
Sources farmers trust	Experienced persons	Fertilizer agents	Other farmers	Other farmers	Experienced male farmers	Field trials

With respect to fertilizer decisions, smallholders in Farm Type 1 trust information provided by experienced people with agricultural background or experience, including extension officers and foreigners. Farmers in Farm Type 2 rely on fertilizer agents for information while farmers in farm types 3 and 4 trust other farmers who are doing well. Female farmers in farm Type 5 look up to experienced male farmers and often ask them for advice. Farm Type 6 farmers are more pragmatic, and one farmer stated that *"I only believe when I can see the outcome"*.

7.3.4 Decision support tools/apps

7.3.4.1 Describing a DST to farmers

After discussing fertilizer decisions and risks, the concept of a mobile-based fertilizer DST was introduced to the FGD groups. A DST was a new concept to smallholders. Although some farmers had not previously heard of a DST, many farmers were aware of agricultural mobile apps and had some understanding of their ability to provide information. The agricultural mobile apps currently available in Myanmar and the functions available were discussed and listed on a flip chart. It became clear that there is no program providing information regarding N fertilizer and yield or cost/benefit calculations that could be made by farmers.

An example prototype of RiseHarvest mobile-based DST was shown to farmers for demonstration purposes (Figure 30). The application was still in testing stage and the recommendations provided were not accurate. However, farmers provided with a general understanding of how the tool operates, shown the information they need to enter and how the recommendations would be delivered based on their data input. Farmers liked the picture icons and the voice features, especially for farmers who could not read. Farmers were confused about why the information needed to be repeated for every season and saw no reason for this information over the long term. Some comments were:

"I'll probably just use it maybe once because the information I'll enter will be the same",
"We often save seeds for the next season so we use the same inputs every time so there won't be any difference".

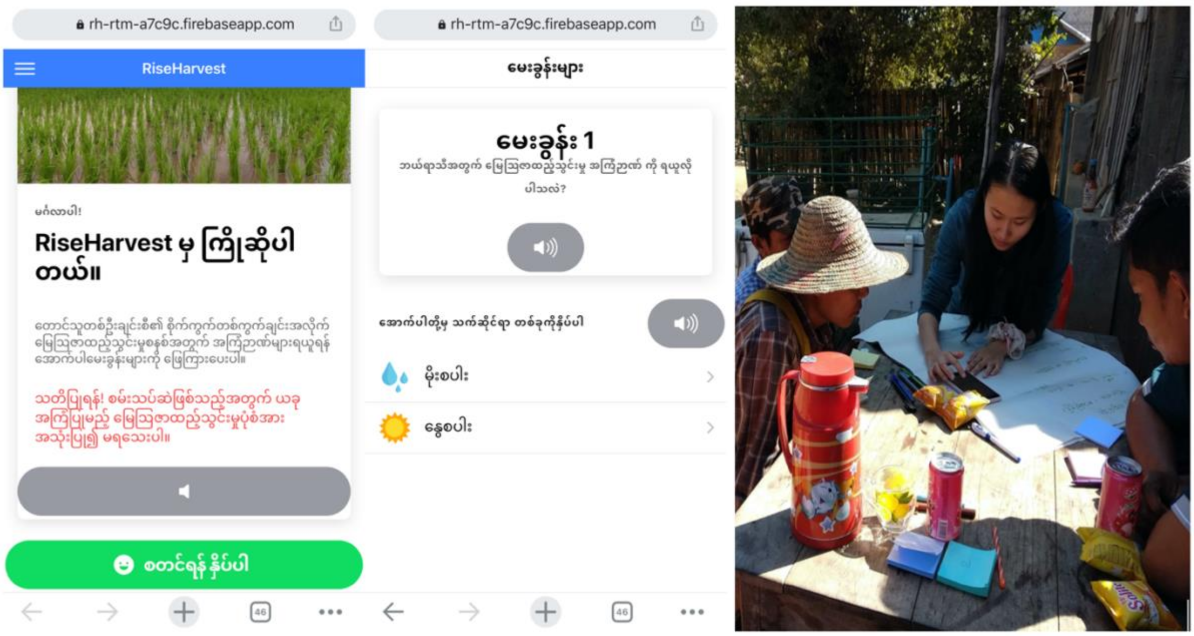

Figure 30. Prototype of RiseHarvest app used to demonstrate the concept of a DST to farmers in central Myanmar

Then farmers were asked ***"what information would be most helpful for you from a DST?".*** The answers varied among and between the farm types (Table 31).

Table 31. Information most helpful to farmers

Farm Types	What information would be most helpful to you from a DST?
Type 1	Pest and disease information
Type 2	Time of application of fertilizer Rates to apply based on symptoms of plant
Type 3	Planting time of crops based on seasonal weather variability Information based on each planting stage
Type 4	Cost-benefit calculation to know profit with the current market price
Type 5	Seasonal weather information Pest and disease information
Type 6	Rate of fertilizer based on soil condition (to reduce the amount) Seasonal weather information

Farmers in **Farm Type 1** were mainly interested in pest and disease information as they had bad experience with pests on rice in the previous years. Farmers were aware of the Plant Protection app (Thar et al., 2020) because they have seen extension officer using it. This app has information about pesticides based on crop type. But farmers prefer to have the extension officer using the app instead of using by themselves.

Some comments were:

"Last year there was an aphid outbreak and farmers were not sure what to do. We asked our local extension officer and she opened an app on her phone and told us what pesticide to use and it was resolved",

"We prefer when extension officers to use app when we ask them because we consider it is like getting a third opinion when we are unsure about our decision or something else".

Farm Type 2 farmers were keen to know more about the signs and symptoms of the plant indicating when fertilizer should be applied. They wanted more information so they can decide themselves and not be given direct information of the time or rate to apply.

Some comments were:

"We use fertilizer based on the plant condition. When the plant is showing some signs such as yellowing of leaf color, we apply fertilizer",

"We only know to apply fertilizer when the plant is yellow. We will like to learn other signs and symptoms of the plant which shows when to apply fertilizer. We will also like to know how much to apply based on what nutrients are deficient, so we don't apply when it's not necessary".

Farmers in **Farm Type 3** had concerns about climate change and preferred information of planting and fertilizer application time based on seasonal weather variability. These changes are having an impact on crop yields and influencing decisions about investing in crop inputs. The uncertainty in crop yields due to climate change is a friction on the use of more crop inputs. The need of drought resistant crop varieties was also raised by farmers. Some comments were:

"We experience crop failure and loss due to irregular weather patterns such as drought during cultivation time and unseasonal rainfall during harvesting time",

"It will be beneficial to us if we can cultivate according to climate variation at each planting stage",

"We are not sure when to start planting as the monsoon season is becoming shorter",

"Because of weather uncertainty, we decide not to add many inputs as we cannot afford to take such risks since most of the inputs were bought on credit".

Cost-benefit calculation to estimate profit was the most important information that farmers in **farm Type 4** wanted in a DST.

Some comments were:

"We will like to know how much we will profit before investing in inputs such as fertilizers",

"These days market prices of crops fluctuate a lot, so it is hard for us to decide if we are going to profit or lose".

Farm Type 5, which were the all-female farmers, also stated the importance of seasonal weather information. Female farmers have raised the issue of not having access to water as they cannot go out to the field at night to pump the water. So, they can only depend on rainwater.

Some comments were:
"We don't have access to water because we cannot go out at nighttime. Male farmers can go out to the field at night to pump water".

Farmers in **farm Type 6** are more commercially orientated and have income sources from businesses (renting machinery, livestock breeding/selling) or from different crops grown, providing offsetting oncome. Therefore, they can take risks. They can also afford tube wells, so they depend less on rain or water from dam to irrigate their fields.
Some comments were:
"I know I use more fertilizer than other farmers, but I don't want to reduce the amount because I don't know how much exactly I need to put based on the plant and soil condition, so I always put more. So, a fertilizer DST can be beneficial for me because, it might help me to reduce the use of fertilizer",
"I have 6 wells where I can pump water to irrigate my fields so I don't count on rain but strong winds during flowering time can damage crops. It would be good if we can know earlier to prevent".

*7.**3.4.2 Farmers opinions on fertilizer DSTs***

Farmers were asked questions relating to their preferences for information access, including their intention to use the DST and whether they thought it would be beneficial. These were asked to find their opinions about DSTs. The results are provided in Table 32. Farmers in Farm Type 2 were optimistic and thought that the DSTs may be useful in allowing them to gain more information and knowledge. They appeared potential to adopt the fertilizer DST than other farmers. Farmers in Type 1 showed slight interest in the tool. Some cultural barriers were noted by farmers in Farm Type 3, such as farmers not taking phones to the field because they wear longyi (traditional outfit worn by men in Myanmar) which lacks pockets. Lack of digital literacy and quality of the mobile phones were also mentioned as reasons against using the tools. Comments from farmers in types 4 and 5 (Table 32) were inconsistent with the DSTs developed with crop yield targets and based on N budgeting approaches.

Hence, a new paradigm for thinking about fertilizer decisions can be considered.

In addition, when farmers were asked ***"how do you want the information delivered?",*** they were not keen on a prescriptive DST, i.e., a tool developing a specific recommendation of how much fertilizer to use. Instead, farmers interested in the technology considered that discussion groups were a better learning environment and preferred a learning-based tool rather than a prescription-based tool. Some comments were:

"We don't like to be told how to manage our field we will like to learn",
"We prefer discussion support because we can discuss and ask specific questions or seek new ideas with other farmers",
"Allowing us to discuss with other farmers can prevent us from misinterpreting because these apps and tools are still new to us",
"I may not continue to use the apps by myself, but I am happy to maintain regular discussions with other farmers".

Table 32. Farmers opinion on fertilizer DSTs

Farm Types	***Farmers opinions on fertilizer DSTs***	
	Optimistic opinions	***Pessimistic opinions***
Type 1	*"I will use if it is not complicating"* *"Images and video clips are more interesting"* *"I will use if I don't have to open internet"*	*"We have seen extensions officer using agri mobile apps but I prefer to have them use and look for us because I am afraid that I will misinterpret"* *"We don't need recommendation on fertilizer, we need recommendation on pest and diseases"*
Type 2	*"it will be useful, so we don't have to wait for extension officers who do not come often"* *"I am open to learn new technology"* *"Anything that will assist with our farming, we are open to it"* *"Our ancestors have been farming the traditional ways with less profit and it is time to change"* *"I am happy to pay for internet if it is going to benefit our farming because we use it for Facebook anyways"* *"We can gain knowledge and new information"* *"I have good experience with agri apps"*	
Type 3		*"I will read information, but I won't use it regularly"* *"Phone screen is too small to read"* *"We wear longyi so don't have a place to put phone while we are working in the field"* *"We leave phone at home when we go to the field so that it doesn't get stolen when we are in field"*
Type 4		*"There are a lot of many new apps, no space in phone"* *"market price of rice is very low these days so we can't follow recommendations even if we want to"* *"we have to apply what we can afford"* *"market price is more important because we won't get profit if the market price is low even with high yield"*
Type 5		*"We will not use because we don't know how to"* *"We don't have time to learn to operate apps because we also have other housework and have to look after children"* *"we will like to learn through video clips not apps"* *"some recommendations are costly and not useful"*
Type 6		*"agri apps give generalized recommendations which are not specific to my fields"*

Discussion Support is a collaborative approach between farmers, whereas Decision Support is a more prescriptive approach providing recommendations which can be misinterpreted. Discussion Support can be used by individual farmers, groups of farmers, or a group of farmers with extension officers enabling discussion of alternative management decisions, asking specific questions, and seeking new ideas about adjusting farm decisions to meet smallholder management objectives. Table 33 shows differences between Decision Support and Discussion Support.

Table 33. Difference between decision support and discussion support

Decision Support	**Discussion Support**
Prescriptive approach	Collaborative approach
Prescription-based tool	Learning-based tool
Easy to misinterpret	Ask specific questions/ seek new ideas
Trust issues	Less trust issues
No interaction between other farmers	Interactive and can share knowledge
Moderate/High digital literacy	Low digital literacy

Farmers emphasized their preference for video clips and infographics integrated in digital platforms, including social media and existing agricultural apps. Female farm type members mentioned video clips being more practical and entertaining for them. Some comments were:

"Video clips are good for us because we can watch at our free time",

"It is also entertaining, and we gain knowledge".

Videos can reach many people and Afroz and Singh (2018) found that farmer videos were more convincing to farmers than extension officers talking. Bently and Mele (2011) stated that farmers enjoy learning from farmers further away even if they are from different countries. Participatory videos, with farmer participation, can be suitable for delivering new technology to farmers in their language with their participation.

7.4 Conclusion

Given the likely increased future demand for digital services, these results can help to identify farm system types when considering the introduction of mobile-based tools. Six farm types were identified with different attitudes about mobile-based DSTs. Although the participating farmers had no prior knowledge of DSTs, they readily engaged in examining the DST example, and provided considered opinions. Only farmers in one farm group (Type 2) were optimistic about DSTs and more focus could be given in the introduction and training of such digital tools to these types of farmers. These results can assist consideration of mobile-based DSTs for different farmer types. These results provide an improved understanding of farmer beliefs and attitudes towards DSTs and will assist the development of DSTs according to the needs of specific farmers. They can help implement policies for digital extension services to further support smallholders in Myanmar.

An important finding is that the concept of decision support in providing prescriptive advice was inconsistent with what many farmers want. Farmers in all six farm types identified that a discussion support format is more useful. They believe that discussion groups provide a better learning environment and prefer a learning-based tool rather than a prescription-based tool. Smallholders, especially female farmers, preferred video clips and infographics integrated into digital platforms, including social media and existing agricultural mobile applications. We conclude that incorporating participatory research framework with typology identification is potentially valuable in assessing potential for new technologies and may have a beneficial role in direct interactions with smallholders which may increase their acceptability towards DSTs.

The contribution of the study is identification of distinct groups or types of farmers among a heterogeneous farmer population so that DST can be designed to reflect farmer needs and target appropriate end users. Previous studies have utilized various participatory approaches with farmers but have not accounted for complexity of heterogeneous smallholder farming systems. The statically robust method and subsequent development of a more detailed understanding of fertilizer decisions and risks through FGDs is important information. The results include knowledge of, and intentions related to, DSTs and Apps. This study has generated valuable information about farmer types and serves as a starting point for developing a framework for discussion support systems which may better relate to the needs of farmers.

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Chapter 8
Discussions and Conclusion

8.1 Key findings and contributions

The main objective of this research was to better understand Myanmar farmers' fertilizer use and management decisions and to develop a framework for a mobile-based tool that is accepted and utilized by farmers in Myanmar. This thesis addressed three specific research questions as below. The key findings and novel contributions of each chapter are described in detail under each question.

1. ***Are the reported data on the low levels of fertilizer use by smallholders generally true in the case of central Myanmar and how their fertilizer application timing practices compared with the recommended "good management practices"?***

The study highlighted the fertilizer practices of smallholders in the study area by comparing the application rates with the national government agricultural agency recommendations and comparing the timing of fertilizer application against recommended "good management practice". The results of a 600-smallholder survey revealed that 99% of the smallholders in the study area were using fertilizers. Smallholders were found to understand the response of crop yields to basal and split fertilizer applications of N. They apply compound fertilizers to ensure that other nutrients, apart from N, are not limiting. The average fertilizer application rates were also found to be substantial. For urea applied to monsoon rice, 45% of surveyed smallholders applied an average of 100 kg N/ha in three applications and 39% applied 76 kg N/ha in two applications. Hence, the reported national level data and farm-level research, implying low fertilizer use by Myanmar rice farmers is not confirmed by this contemporary study in central Myanmar.

Smallholders were found to be applying substantially lower N levels than the recommendations for maize. Limited access to credit for maize farmers was one of the reasons for the low use as well as cash flow implications.

On the other hand, smallholders are rational; they have good reasons for doing what they do. Farmers applying no fertilizer may be in a subsistence mode and those who are using fertilizers are in a semi-subsistence or commercial mode. An understanding of the economics and risk associated with farm-level decisions is important when considering practices of farm input usage by smallholders.

With respect to fertilizer application timing, the survey results showed that smallholder practices were generally aligned with the first three N timing aspects of the "good management practices". However, nearly half of the surveyed farmer practices did not align with the fourth practice (apply N at P.I. stage). This was a very important recommendation for farmers in the study area in Myanmar. With respect to P timing, most farmers were applying throughout the growth stages when earlier applications are recommended. Smallholder farmers may also be able to save the cost of labor for fertilizer application by reducing the number of P applications and avoiding late application.

However, these results should not be considered representative of Myanmar as the study area was found to have higher than average access to input retailers and support services. Overall, these farmers are using better fertilizer management than indicated by the literature and thus, the hypothesis that 'farmers in central Myanmar fertilizer management is deficient' was rejected. Careful consideration is required to improve smallholder fertilizer management in Myanmar. Specific policies in relation to fertilizer use such as emphasizing the implementation methods and reducing over fertilization as well as using quality seeds and better credit access for maize farmers were suggested by the study.

2. ***What are farmers intentions to use agricultural mobile apps for farm decision making and what socio-economic factors influence their use?***

According to the study, farmers were optimistic about agricultural mobile apps with over 70% of the farmers in the study area willing to use them. However, only 21% of the farmers were currently using these apps, with a majority (56%) only opening them once a month. The main reasons for such low use of mobile apps for farm decision making were lack of awareness and knowledge, along with the high cost of internet. The positive attitude towards agricultural mobile apps and negative usage level of most respondents in the study seems a challenge in introducing mobile-based agricultural support tools.

An interesting finding from the study was that a majority of the surveyed farmers (54%) were familiar with information received through Facebook groups. Since Facebook has established trust and the majority of the smallholder farmers were using it, incorporating useful information and functions from an agricultural mobile app to a Facebook Page could have a more useful and sustainable impact. This would also alleviate issues such as lack of awareness, lack of use, and long-term servicing and sustainability.

In order to analyze the socioeconomic factors influencing the use of agricultural mobile apps, the binary Probit model was employed to the survey data set. Our empirical results demonstrated that socio-economic factors such as age (negatively), education (positively), degree of mechanization (positively), number of crops (negatively) and market distance (negatively) were found to affect the use of agricultural mobile apps. Thus, both the research hypotheses, 'socio-economic factors are important for the use of agricultural mobile apps' and 'different socio-economic factors may have a causal relationship with the use of agricultural mobile apps' were accepted. Hence, it is suggested that when introducing mobile-based agricultural support tools, focus should be given to younger, educated farmers with more specialized crops as early adopters. The study results contribute to assisting international, private and public sector organizations in developing and scaling up agricultural mobile apps to be effectively utilized by Myanmar farmers.

3. ***Whether different farm types exhibit significantly different patterns in the intention to adopt mobile based DSTs and what are farmers' opinion and acceptability towards these tools to assist with fertilizer decisions in Myanmar?***

The typology analysis identified six different farm types which exhibited different patterns in the adoption of mobile-based DSTs. Thus, the hypothesis that 'different farm types have different opinions towards use of mobile based DSTs for fertilizer management' was accepted.

Participatory research through focus group discussions validated the farm typologies and provided evidence that farmers belonging to one type (large and semi-intensive, on farm) considered that DSTs could be useful in gaining more information and knowledge. These farmers were more likely to adopt a fertilizer DST than other famer types and more focus could be given in the introduction and training of digital tools to these types of farmers. Farmers in other farm types expressed their interest of a DST for other management practices such as pest and disease management instead of fertilizer.

The interaction with farmers from the study showed that the concept of DST in providing prescriptive advice was inconsistent with what many farmers actually want. Farmers in all six groups felt that discussion groups were more likely to be a better learning environment and preferred a learning-based tool rather than a prescription-based tool. Discussion Support is a collaborative approach between farmers, whereas Decision Support is a more instructive approach providing recommendations which can be misinterpreted. Discussion Support can be used by individual farmers, groups of farmers, or a group of farmers with extension officers enabling discussion of alternative management decisions, asking specific questions and seeking new ideas about adjusting farm decisions to meet smallholder management objectives. Farmers, especially female farmer, emphasized their preference for video clips and infographics being integrated into digital platforms including social media and existing agricultural mobile applications. This study has generated valuable information about farmer types and serves as a starting point for developing a framework for discussion support systems enabling targeted deployment of a tool by potential developers which is better relate to the needs of farmers. We concluded that incorporating participatory research frameworks with typology identification is potentially valuable in assessing new technologies and may have a beneficial role in direct interactions with smallholders.

The contribution of the study is identification of distinct groups or types of farmers among a heterogeneous farmer population so that DSTs can be designed to reflect farmer needs and target appropriate end users. Previous studies have utilized various participatory approaches with farmers but have not accounted for the complexity of heterogeneous smallholder farming systems. The statically robust method and subsequent development of a more detailed understanding of fertilizer decisions and risks through FGDs is important information. The results include knowledge of, and intentions related to, DSTs and apps. This study has generated valuable information about farmer types and serves as a starting point for developing a framework for discussion support systems which may better relate to the needs of farmers.

8.2 Future research directions

The location of this study was based on the fertilizer yield response trials of the ACIAR project which were located in three townships: Tatkon, Zeyarthiri and Bago townships. Tatkon and Zeyarthri townships are both located within Nay Pyi Taw, the capital of Myanmar and had greater than average access to various agricultural support services such as DoA, Department of Agricultural Research (DAR) and YAU. Hence, farmers' field survey results indicated that the farmers were, to a larger extent, following good fertilizer management practices. Study areas for further research could be located at more remote and under-resourced areas covering a wider landscape. The study mainly focused on applications of urea and compound (N:P:K) fertilizers by smallholder farmers. Further studies on other micro-nutrients, manure, and organic fertilizers can be useful.

This study found that maize farmers in central Myanmar were applying substantially lower N levels than the national recommended rates. Access to credit was identified as one of the main reasons for the low use of fertilizer by farmers. Innovations and policies to improve rural credit access are worth further study.

The empirical results reported for the factors affecting agricultural mobile app use should be considered in the light of some limitations in the explanatory variables used. Including mobile phone use-related attributes (skills of using mobile phone, digital literacy, duration of phone ownership) would be useful for further studies.

The study also suggested incorporating useful information and functions from an agricultural mobile app to a social media platform which has already gained trust from farmers such as a Facebook Page. This approach maybe a more useful and sustainable way, at the same time eliminating the issues of most DSTs such as lack of awareness, lack of use and long-term servicing and sustainability. Myanma Awba, the largest manufacturer and distributor of agricultural technology such as fertilizers and seeds in Myanmar, has over 1.5M Facebook followers including farmers, extension officers, agricultural experts and researchers, wholesalers and retailers. Useful video clips, simple budgeting functions, fertilizer yield response predictions can also be incorporated into the platform for exchanging knowledge and networking among industry stakeholders and farmers. Further studies are required to implement this suggestion.

In addition, discussion support format was reported to be preferred by farmers from the study area. More participatory approaches with farm types are crucial to develop relevant, useful and long-lasting digital solutions.

8.3 Conclusion

This thesis set out to provide a more in-depth detail about smallholder fertilizer practices in central Myanmar and to develop a framework for a mobile-based tool that is accepted and utilized by Myanmar farmers. In the case of smallholders in central Myanmar, there was very little evidence from the field survey in support of the perception that Myanmar farmers are using low levels of fertilizers. The study indicated that the farmers were, to a larger extent, following good fertilizer management practices and decision support should be focused on other management practices instead of fertilizer. This is the first substantive study to compare and clarify how fertilizer management is being conducted by Myanmar smallholders and provides a sound basis for further research and development and agricultural policy considerations in Myanmar.

Moreover, agricultural fertilizer decision support tools (DSTs) have suffered from low levels of use, apparently due to limited acceptability by end users. Many of these tools appear to have been developed from a scientist-based perspective, but recent efforts have been made to include end-user participation in development. Many studies have utilized various participatory approaches with farmers to but have not account for complexity of heterogeneous smallholder farming systems. This study utilized typology analysis, applied to a survey dataset, to identify different farm system types and used qualitative participatory research to assess potential deployment of decision support tools for fertilizer management. Only farmers belonging to one type (large and semi-subsistence, of farm) considered that DSTs could be useful in gaining more information and knowledge. Among these types of farmers, focus should be given to younger, educated farmers with more specialized crops to target as early adopters for the introduction and training of digital tools.

The proposed decision support framework abandons the traditional DST approach, which is considered to be a "black box", complex requiring substantial manual data entry which are not attractive to farmers. Instead, this framework suggests on-going participatory approaches with farmers to gran their trust, integrate their inputs and implement their suggestions, identify specific groups of farmers as early adopters, utilize social media platforms to deliver discussion support outputs which are readily usable in the form of video clips and infographics and develop a discussion support format where farmers can discuss and learn from each other and the wider agriculture community. Considerable care should be taken to ensure that farmers socio-economic factors and decision-making contexts are also considered.

APPENDIX

Appendix I - Survey Questionnaire

Introduction

This survey is being conducted for a PhD research thesis. The survey is related to fertilizer use and decisions. The aim of this survey is to understand how farmers make decisions in regard to fertilizer use to develop a framework for a fertilizer decision support tool which will help farmers to make better informed fertilizer decisions while dealing with agricultural risks associated with under or over application of fertilizer. The information you share with us will not be shared with others in a way in which you can be personally identified. Your participation in the survey is highly valued and it is entirely voluntary. You may choose to withdraw at any time without restricting your involvement to future activities.

1. Do you agree to participate in this survey? *
    - o yes
    - o no

General Information

Village

1. What is the name of the township? *

    - o Zeyarthiri
    - o Tatkone
    - o Taungoo

2. What is the name of the village? *

Respondent (farmer)

3. What is the name of the respondent? *
4. What is the gender? *
    - o Male
    - o Female
5. How old is the respondent? * (years)
6. What is the level of education? * (years)
7. How long have you been working on the farm? * (years)
8. What is your marital status? *
    - o married

- divorced
- widowed
- single
- not applicable (age less than 16)

<u>Household Information</u>

Household

1. How many people are in your household? *
2. How many people are involved in off-farm activities? *
3. What type of off-farm activities do they do? *
    - salary earner at a private firm (e.g., factory/office worker)
    - salary earner at public facilities (e.g., govt. employee, school teacher)
    - casual wage earner (irregular payment)
    - transport business
    - trader
    - work at other country
    - shop owner
    - others
    - no

4. What is the income working at a private firm? (MMK/month)

What is the income working at a public facility? (MMK/month)
What is the income as a casual wage earner? (MMK/month)
What is the income of transport business? (MMK/month)
What is the income as a trader? (MMK/month)
How much do they send back to you? (MMK/month)
What shop is it?
What is the profit from the shop? (MMK/month)
Describe others.
What is the income from that work? (MMK/month)

Livestock

5. Do you have any livestock? *
    - yes
    - no
6. What type of livestock do you have? *
    - cattle
    - chicken
    - pig
    - buffalo
    - duck
7. How many chickens do you have? *
    How many cattle do you have? *

How many pigs do you have? *
How many buffalo do you have? *
How many ducks do you have? *

8. What is the main purpose of having livestock? *
    - farming
    - transport
    - fund child education
    - marriage
    - source of food
    - income
    - others

What is the other purpose of livestock?

Farm tools

- Do you have any tractor? *
    - Yes
    - no
- How many tractors do you have? *

- What kind of tractor is it? *
    - 2-wheel tractor (hand-tractor, gon daung)
    - 4-wheel tractor
- How much did you buy it for? * (MMK)
- How long have you owned it for? (in months) *
- How many threshers do you have? *
- How many sprayers do you have? *
- How many water pumps do you have? *

Land Information

- Do you own the land? *
    - Yes
    - No
- How many acres do you own? * (ac)

- Do you know the texture of soil type? *
    - Yes
    - No
- What is the soil type?

- sandy soil
    - loam
    - silty soil
    - clay soil
- Do you have cracked soil?
    - Yes
    - No
- Do you think your soil is good or bad?
    - Good soil
    - Bad soil
        - Why is it bad soil?
- What is the colour of your soil?
    - Light brown
    - Brown
    - Black
    - Red
- Do you rent out land? *
    - Yes
    - no
- How many acres do you rent out? * (ac)
- Do you rent in land? *
    - Yes
    - no
- How many acres do you rent in? * (ac)
- How much did you pay to rent for one acre? * (MMK/ac)
    - total land check ____

Crop Production Information

- How many crops do you grow in a year? *

Crop Info *(the following questions will repeat depending on the number of crops grown)*
Crop

- What crops do you grow? *
    - Rice
    - Maize
    - Black gram
    - Green gram
    - Sesame
    - Chickpea

- What variety of rice do you grow? *
    - Ma Naw Thuka
    - Htun Thuka
    - Yezin Thuka
    - Yezin 2
    - Sin Thuka
    - Sin Thwe Latt
    - Shwe Thwe Yin
    - Shwe Toe (90 days)
    - Ma Gyan Taw
    - Gyan Aye Yar
    - Shan Aye Yar
    - Aye Yar Min
    - Aye Yar Ba Day Thar
    - Palal Thwe
    - Paw San
    - Paw San Bay Gyar
    - Byow Htun
    - Thai 90
    - Dagon 2
- What variety of rice do you prefer to grow?

- What variety of maize do you grow? *
    - CP 888
    - Thai Variety
    - Yezin Variety
    - Sweet Corn (Pan Shwe)
- What variety of maize do you prefer to grow?

- What variety of black gram do you grow? *
    - HYV (Si Pe, Ywet Shun)
    - Yezin Variety
    - Local Variety (Yan Pe, Palal Net)
- What variety of black gram do you prefer to grow?
-
- What variety of green gram do you grow? *
    - Yezin Variety
    - Local Variety
- What variety of green gram do you prefer to grow?

- What variety of sesame do you grow? *
    - Samon Net

- Sin Yadanar
  - Yezin Variety
- What variety of sesame do you prefer to grow?
- What variety of chickpea do you grow?
  - Local variety
  - HYV
  - Taiwan variety
- What season do you grow in? *
  - summer
  - monsoon
  - winter
- How many acres do you grow? (total acre cultivated) *
- Is the land irrigated or rainfed? *
  - irrigated
  - rainfed
  - both
- What area is irrigated? *
- What area is rainfed? *
- Where did you get the seed from? *
  - own seed
  - DAR
  - IRRI
  - village shop
  - town shop
  - other farmer
  - others

    Describe others

- How much seed did you use for one acre? *
- What is the unit of the seed used for one acre? *
  - bsk/ac
  - viss/ac
  - pyi/ac
  - tonne/ac

  - total seeds check____

- How much seed did you buy in total? *
- What is the unit of the seed bought? *
  - bsk
  - viss
  - pyi
  - tonne

- How much was the cost of the seed you bought? * (MMK/unit) 15

Labor

- What do you use for ***land preparation***? *
    - manual (with cattle/ox)
    - tractor
    - both
    - no land preparation
- Is the tractor owned or hired? *
    - owned
    - hired
    - both
- How much is the tractor fee? * (MMK)
- What labor did you use for land preparation? (including cattle/ox) *
    - family labor
    - hired labor
    - both
- How many people from family did you use for land preparation? (including cattle/ox - for one acre) *
- How many days did you use family labor for land preparation? (days)
- How many people did you hired for land preparation? (including cattle/ox - for one acre) *
- How much did you pay for hired labor for land preparation? *
- How many days did you hired labor for land preparation? *

- Was the crop transplanted or broadcasted? *
    - transplanted
    - broadcasted
    - both
- What labor did you use for ***crop establishment***? *
    - family labor
    - hired labor
    - both
- How many people from family did you use for crop establishment? *
- How many days did you use family labor for crop establishment? *
- How many people did you hired for crop establishment? *
- How much did you pay for hired labor for crop establishment? *
- How many days did you hired labor for crop establishment? *

- Do you use ***manure***? *
    - yes
    - no
- How much manure did you use for one ac? * (cart)
- Do you buy manure? *

- yes
- no (own)

➢ How much does it cost? * (MMK/cart)

➢ Do you use ***fertilizer?*** *

- yes
- no

➢ What type of fertilizer do you use? *

- Urea
- Compound
- T Super
- Gypsum
- Foliar

Urea

➢ What is the brand of the fertilizer you use? *

- Armo
- Awba
- Top One
- Shwe Nagar
- Shwer Taung
- Golden Lion
- Golden Key
- China Brand
- Thai Brand
- Wi Sara
- Yuzana
- Ki Mi Yar
- Comet

➢ How much is a bag of fertilizer? (MMK/bag)

➢ How many kgs in one bag of fertilizer that you applied? (kg/bag)

➢ Where did you buy the fertilizer? *

- direct from company
- from township market
- from village shop
- from fertilizer agent
- from another farmer

➢ Do you buy cash or credit? *

- cash
- credit

➢ Do you apply ***basal application***? *

- yes
- no

- Why don't you practice basal application? *
- How much did you apply? (kg) *
- How much did you wish to apply? (kg) *
- Why?

- Do you practice ***split application***? *
  - yes
  - no
- Why don't you practice split application? *
- How many times did you apply? *
  - once
  - twice
  - three times
- How many days after cultivation did you apply your first urea application? * (days)
- How much did you apply? (kg) *
- How much did you wish to apply? (kg) *
- Why?
- How many days after cultivation did you apply your second urea application? * (days)
- How much did you apply your second urea application? *(kg)
- How much did you wish to apply? *(kg)
- Why?
- How many days after cultivation did you apply your third urea application? * (days)
- How much did you apply your third application? (kg) *
- How much did you wish to apply? *(kg)
- Why?

Compound

- What is the brand of the fertilizer you use? *
  - Armo
  - Awba
  - Top One
  - Shwe Nagar
  - Shwer Taung
  - Golden Lion
  - Golden Key
  - China Brand
  - Thai Brand
  - Wi Sara
  - Yuzana
  - Ki Mi Yar
  - Comet

- What is the nutrient ratio of the compound fertilizer?

- 10 10 10
- 15 15 15
- 21 7 18
- 19 9 19
- Do not know
- Others _ Describe others

- ➢ How much is a bag of fertilizer? * (MMK/bag)
- ➢ How many kgs in one bag of fertilizer that you applied? * (kg/bag)
- ➢ Where did you buy the fertilizer? *
  - direct from company
  - from township market
  - from village shop
  - from fertilizer agent
  - from another farmer
- ➢ Do you buy cash or credit? *
  - cash
  - credit
- ➢ Do you apply basal application? *
  - yes
  - no
- ➢ Why don't you practise basal application? *
- ➢ How much did you apply? (kg) *
- ➢ How much did you wish to apply? (kg) *
- ➢ Why?

- ➢ Do you practise split application? *
  - yes
  - no
- ➢ Why don't you practise split application? *
- ➢ How many times did you apply? *
  - once
  - twice
  - three times
- ➢ How many days after cultivation did you apply your first compound application? *(days)
- ➢ How much did you apply? (kg) *
- ➢ How much did you wish to apply? (kg) *
- ➢ Why?
- ➢ How many days after cultivation did you apply your second compound application? * (days)
- ➢ How much did you apply your second application? (kg) *
- ➢ How much did you wish to apply? *(kg)

- Why?
- How many days after cultivation did you apply your third compound application? *(days)
- How much did you apply your third application? (kg) *
- How much did you wish to apply? * (kg)
- Why?

T Super

- What is the brand of the fertilizer you use? *
    - Armo
    - Awba
    - Top One
    - Shwe Nagar
    - Shwer Taung
    - Golden Lion
    - Golden Key
    - China Brand
    - Thai Brand
    - Wi Sara
    - Yuzana
    - Ki Mi Yar
    - Comet
- How much is a bag of fertilizer? (MMK/bag)
- How many kgs in one bag of fertilizer that you applied? (kg/bag)
- Where did you buy the fertilizer? *
    - direct from company
    - from township market
    - from village shop
    - from fertilizer agent
    - from another farmer
- Do you buy cash or credit? *
    - cash
    - credit
- Do you apply basal application? *
    - yes
    - no
- Why don't you practice basal application? *
- How much did you apply? (kg) *
- How much did you wish to apply? (kg) *
- Why?

- Do you practice split application? *
    - yes
    - no

- Why don't you practice split application? *
- How many times did you apply? *
  - once
  - twice
  - three times
- How many days after cultivation did you apply your first T super application? * (days)
- How much did you apply your first T super application? (kg) *
- How much did you wish to apply? (kg) *
- Why?
- How many days after cultivation did you apply your second T super application? *(days)
- How much did you apply your second T super application? (kg) *
- How much did you wish to apply? *(kg)
- Why?
- How many days after cultivation did you apply your third T super application? * (days)
- How much did you apply your third T super application? (kg) *
- How much did you wish to apply? *(kg)
- Why?

Gypsum

- What is the brand of the fertilizer you use? *
  - Armo
  - Awba
  - Top One
  - Shwe Nagar
  - Shwer Taung
  - Golden Lion
  - Golden Key
  - China Brand
  - Thai Brand
  - Wi Sara
  - Yuzana
  - Ki Mi Yar
  - Comet
- How much is a bag of fertilizer?
- How many kgs in one bag of fertilizer that you applied? *
- Where did you buy the fertilizer? *
  - direct from company
  - from township market
  - from village shop
  - from fertilizer agent
  - from another farmer
- Do you buy cash or credit? *

- cash
- credit

- Do you apply basal application? *
  - yes
  - no
- How much did you apply? *
- Do you practise split application? *
  - yes
  - no
- Why don't you practise split application? *
- How many times did you apply? *
  - once
  - twice
  - three times
- When did you apply? (how many days after cultivation did you apply?) *(days)
- How much did you apply? * (kg)
- When did you apply your second application? (how many days after cultivation did you apply?) * (days)
- How much did you apply your second application? *(kg)
- When did you apply your third application? (how many days after cultivation did you apply?) *(days)
- How much did you apply your third application? *(kg)

Foliar

- What is the brand of the foliar?
- How much is a bottle of foliar?
- How many kgs in one bottle of fertilizer that you applied?
- How many times do you apply foliar?
- How many days intervals do you apply the foliar fertilizer?
- How much do you apply foliar fertilizer? (amount/interval)

- What sort of **labor do you use for fertilizer** application? *
  - family
  - hired
  - both

- How many people from family do you use to apply the fertilizer for one acre? *
- How many people do you hire to apply the fertilizer for one acre? *
- How much do you have to pay for the hired labor to apply fertilizer? *

- Do you practise ***weeding***? *
  - yes

- no

- How do you practise weeding? *
  - use herbicides
  - manual
  - both
- How much did you pay for herbicides in total?
- What labor did you use for weeding? *
  - family labor
  - hired labor
  - both
- How many people from family did you use for weeding? *
- How many days did you use family labor for weeding? *
- How many people did you hired for weeding? *
- How much did you pay for hired labor for weeding? *
- How many days did you hired labor for weeding? *

- Do you use ***pesticides***? *
  - yes
  - no
- How much did you pay for pesticides in total? (MMK)

- What labor did you use for pesticide application? *
  - family labor
  - hired labor
  - both
- How many people from family did you use for pesticide application? *
- How many days did you use family labor for pesticide application? *
- How many people did you hired for pesticide application? *
- How much did you pay for hired labor for pesticide application? *
- How many days did you hired labor for pesticide application? *

- What do you use for ***harvesting***? *
  - manual
  - harvester
- What labor did you use for harvesting? *
  - family labor
  - hired labor
  - both
- How many people from family did you use for harvesting? *
- How many days did you use family labor for harvesting? *
- How many people did you hired for harvesting? *
- How much did you pay for hired labor for harvesting? *
- How days did you use hired labor for harvesting? *
- How much does it cost to rent the harvester? *

Yield/Marketing

- ➢ What was your yield? (per acre) *
- ➢ What is your total yield? *

    - ❖ total production check ____

- ➢ What did you do with your yield? *
    - kept for home consumption
    - kept for next cropping
    - sold immediately after harvest
    - store to sell later
    - others

        Describe others *

- ➢ How much did you keep for home consumption? * (bsk)

    How many bsk did you keep for next crop? * (bsk)

    How many bsk did you store? * (bsk)

    How long did you store for? * (months)

    How many bsk did you sell? * (bsk)

    How much did you sell it for? * (MMK/bsk)

- ➢ Who did you sell it to? *
    - trader
    - miller
    - private business
    - final consumer
    - broker
    - wholesaler
    - others

        Describe others *
- ➢ Do you have a choice of traders to sell your crop to? *
    - yes
    - no
- ➢ How many traders can you choose from? *
- ➢ Where did you sell? *
    - own village
    - nearby village
    - closet town
    - Yangon
    - elsewhere in Myanmar
    - export to another country
- ➢ What is the commonly practiced mode of sale? *
    - picked up from farmer's house

- delivered to buyer's place

- How much was the transportation cost? *
- What is the unit? *
    - MMK/ac
    - MMK/bsk
    - MMK/pyi
    - MMK/ton

<u>Fertilizer Information</u>

- Does the farmer use any fertilizer on their crop(s)? *
    - yes
    - no
- Do you want to use more fertilizer?
    - yes
    - no
- Do you use less fertilizer because of these factors?
    - expensive in price
    - no knowledge
    - weather uncertainty (drought, rainfall)
    - others. Describe others.

Fertilizer Experience

- How long have you been using fertilizer? *
- What makes you start using fertilizer? *
    - Low yield
    - Other farmers start using fertilizer
    - Plant growth
    - Recommended by Agri-extension staff
    - TV advertisement
    - Recommended by shop
    - Recommended by agent of fertilizer company
- What do you look at when you buy fertilizer? *
    - Label
    - Fertilizer size of pallets
    - Price
    - Advice from other farmers
    - Advice from Agri-staff
    - Tv advertisement
    - Suggestion from fertilizer shop
    - Suggestion from agent of fertilizer company
    - Free Samples
- How many suppliers have you had? *

- What cause you to change the supplier of fertilizer? *
- Do you want to change your current supplier of fertilizer? *
  - yes
  - no
- Do you think yield increase by using fertilizer? *
  - yes
  - no
- To what percentage of yield do you think is increased by using fertilizer? *
- What problems do you face while buying fertilizer?
- Can you always buy the required amount of fertilizer that you want? *
  - yes
  - no
- How long do you have to wait? *

Fertilizer Knowledge

- Do you know when and how often to apply fertilizer systemically?
  - yes
  - no
- How do you know how much or how often to apply fertilizer?
  - agricultural extension staff
  - staff from fertilizer company
  - staff from NGO
  - personal decision
  - read label
  - other farmer suggestion
- Do you think it is best to split fertilizer applications rather than apply all at once?
  - strongly agree
  - agree
  - neither agree/disagree
  - disagree
  - strongly disagree
- Do you think Urea application boosts plant growth and tillering?
  - strongly agree
  - agree
  - neither agree/disagree
  - disagree
  - strongly disagree
- Do you think yield is higher with basal application?
  - strongly agree
  - agree
  - neither agree/disagree
  - disagree
  - strongly disagree
- Do you do anything else to increase soil fertility?

- use kitchen wastes/plant wastes
- use FYM
- crop rotation

➢ Do you know about fake fertilizers?
  - yes
  - no

➢ Are you happy with the fertilizer quality?
  - yes
  - no

➢ Can you report bad quality fertilizer to the government?
  - yes
  - no

➢ Does the quality of the fertilizer you use matter to you?
  - yes, it is very important
  - yes, but it is not very important
  - no

Not use Fertilizer

➢ Why do you not use fertilizer?
  - expensive
  - no knowledge
  - use other source
  - others

    Describe others

➢ Do you want to start using fertilizer?
  - yes
  - no

➢ What other sources do you use instead of fertilizer?

<u>Financing Information</u>

Borrow money for fertilizer

➢ Do you borrow money (loan) to buy fertilizers?
  - yes
  - no

➢ What are the sources of loan?
  - MADB
  - Money Lender
  - Financial Institution
  - Fertilizer or seed seller
  - Family, friends or neighbors
  - Others

MADB

- How much did you borrow from MADB? (total) (MMK)
- What is the interest rate of MADB?
- What is the loan period? (months)
- Is the loan period sufficient to pay back?
  - yes
  - no
- How many months do you think would be sufficient for you to pay back?

Money lender

- How much did you borrow from money lender? (total) (MMK)
- What is the interest rate of money lender?
- What is the loan period? (months)
- Is the loan period sufficient to pay back?
  - yes
  - no
- How many months do you think would be sufficient for you to pay back?

Financial Institution

- How much did you borrow from financial institution? (total) (MMK)
- What is the interest rate of the financial institution?
- What is the loan period? (months)
- Is the loan period sufficient to pay back?
  - yes
  - no
- How many months do you think would be sufficient for you to pay back?

Fertilizer or Seed Seller

- How much did you borrow from the fertilizer or seed seller? (total) (MMK)
- How much did you pay back the fertilizer or seed seller? (MMK)
- What is the interest rate of the fertilizer or seed seller?
- What is the loan period? (months)
- Is the loan period sufficient to pay back?
  - yes
  - no
- How many months do you think would be sufficient for you to pay back?

Family, Friends or Neighbours

- How much did you borrow? (total) (MMK)
- What is the interest rate?
- What is the loan period? (months)
- Is the loan period sufficient to pay back?
  - yes
  - no

- How many months do you think would be sufficient for you to pay back?

Other Loan Source

- What is the other source of loan?
- How much did you borrow? (MMK)
- What is the interest rate?
- What is the loan period? (months)
- Is the loan period sufficient to pay back?
  - yes
  - no
- How many months do you think would be sufficient for you to pay back?

Borrow money for other crop inputs

- Do you borrow money (loan) to buy other inputs?
  - yes
  - no

Repeat questions

<u>Gender/Decision Information</u>

- Who decides what crops to grow? *
  - Male
  - Female
  - Both
- Who decides whether to use fertilizer? *
  - Male
  - Female
  - Both
- Who decides the amount and time of fertilizer? *
  - Male
  - Female
  - Both
- Who decides to borrow money? *
  - Male
  - Female
  - Both
- Who borrows the money? *
  - Male
  - Female
  - Both
- Who decides what livestock to raise? *

- Male
- Female
- Both

➢ Who make household decisions? *
  - Male
  - Female
  - Both

➢ Are any decisions made by female? *
  - yes
  - no

  What are those?

Mobile Phone Information

➢ Do you have a phone? *
  - yes
  - no

➢ What is your phone number?

➢ What type of phone is it?
  - touch phone (smart phone)
  - keypad phone (basic phone)

➢ Can you access the internet easily?
  - yes
  - no

➢ Please rate the internet network connectivity.
  - Very good
  - Good
  - Standard
  - Bad
  - Very bad

➢ Are you aware that there are mobile apps that can help you with your farm decisions? *
  - yes
  - no

➢ What type of apps do you use to help with farming?
  - Green way
  - Golden paddy
  - Ooredoo site pyo
  - others

➢ Describe others

➢ How often do you use them?

➢ Do you find mobile apps useful?
  - yes

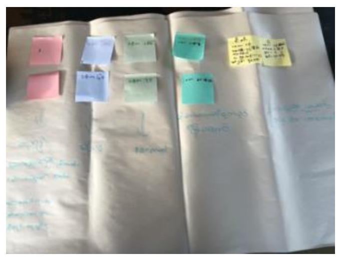
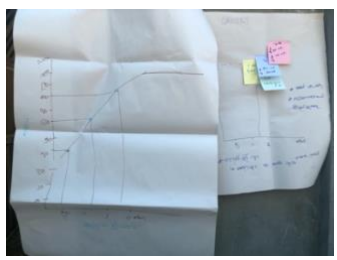
- no

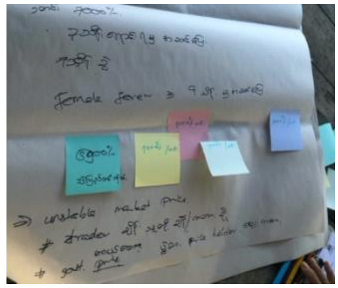
- What do u like about mobile apps?
- Are you keen to follow the recommendation suggested by mobile app?
  - yes
  - no
- Why not?
- Do you have any issues?
  - no network
  - low connectivity
  - cost
  - others
- Please state other issues.
- How much do you spend a month for mobile phone use? (MMK/month)
- Would you prefer guidance that is delivered via
  - mobile
  - paper
  - person

GIS Information

- Where is the village?
- Where is your field?

Appendix II - Focus Group Discussion Protocol

Introduction Farmers were informed about the aim of the research and their consent to participate in the focus group discussion was taken. (5 min) (asked each participant to sign consent form)	
Icebreaker to build rapport (5 min) Six coloured sticky notes were given numbers from 1 to 6 and individual farmer was asked to select a number. The sticky note with the number the farmer received was given to each farmer.	 
Typology Validation (10 min) Farmers were asked about their land ownership, off farm income, livestock and machinery ownership and crops they cultivate.	
Fertilizer questions (20 min) Farmers were asked if they use any fertilizer to monsoon rice. Farmers were further asked if they know the fertilizer recommended rates set by DoA. The relationship between yield and fertilizer (N rates) were explained to farmers with a diagram. Later farmers were asked to write on their own sticky notes, the amount of fertilizer they use on rice for one acre and the yield that they obtained. Farmers who needed assistance with helping was writing was helped by the assistant. Most farmers were able to write on their own. Farmers answers were placed on a graph, so farmers were able to see that farmers apply different rates and even if some applied the same rates, they receive different yield. The reasons for different yields were asked to the farmers. Why they think they obtained less/ more yield.	 

Investment on fertilizer questions (15-20 min) Farmers were asked if they borrow money to buy fertilizers. Farmers were asked to tick (√) on the sticky notes if they borrow money and cross (X) if they don't. If farmers borrow fertilizer, the source of loan and the interest rates were asked. Farmers were asked to write individually on their sticky notes the amount of $$ extra they would require to be able to repay back the loan + interest. The results were discussed. Farmers where ask about the important factors they consider in making these investment decisions and where ask to rate their willingness to take risks for making decisions 1 strongly disagree and 5 strongly disagree.	 
Decision support questions (20 min) Farmers were asked if they know any agricultural mobile apps currently available in Myanmar. The functions available in the apps were discussed and listed down on the flip chart. From the listed functions, an emphasis that there is no function that provide information regarding N fertilizer in Myanmar was made. The farmers were explained about the concept of a fertilizer decision support tool/app to help them with their decisions for fertilizer management. A prototype of a fertilizer DST was shown to farmers as an example. Questions on farmers opinions and acceptance of DST were also asked.	
Conclusion Farmers were acknowledged for their participation and were given 3000 MMK (AUD 3.20) for their time involved in the discussions. The payment is considered to compensate farmers for taking their time from work and also for transportation to the FGD location.	

Farmer Types

Type 1	
Type 2	
Type 3	

Type 4		
Type 5		
Type 6