Digitally-enabled crop disorder management based on farmer empowerment for improved outcomes

By

Janagan Sivagnanasundaram

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AUTHENTICATION

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

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Janagan Sivagnanasundaram

ABSTRACT

Crop disorder incidents such as pests and disease attacks are the major reason of crop losses that require timely actions and can adversely affect agriculture production. In order to address this problem, a model was designed that empowers farmers to identify crop disorder incidents instantly and manage them effectively by providing relevant information in context. In contrast, the existing approaches reported in the literature rely on identifying crop disorders from images that depict the presence of symptoms in the crop. However, due to the inherent characteristics of the images, these approaches are effective only in more controlled environments and provide limited support in crop disorder identification.

We have created a crop disorder search space model that is composed of mapping between different crop disorders and symptom(s) that provide unique identification characteristics specific to each crop disorder. We call these unique mappings as disorder identifiers. This model was later converted into a mobile-based artifact, and the information required to perform the search operation on the search space was obtained from farmers through it. The artifact was deployed among a group of farmers to evaluate how well it could aid in identifying crop disorders. It was noted that the developed artifact was able to identify most crop disorders instantly, mitigating the issues associated with crop disorder identification. In the rest of the cases, it gives subject experts the ability to identify crop disorders.

The experiments conducted on the effectiveness and usability of the artifact indicate that disorder identifiers providing clear and consistent representations of the presence of crop disorders can be used to identify them rapidly. Further, it has been also demonstrated that farmers are capable of correlating their field observations with a list of crop disorder identifiers provided through the artifact. The correct selection of the disorder identifier will lead farmers to know about the presence of crop disorder in the field and recommend control measures instantly. Moreover, farmers' perception of various impact indicators showed that, as compared to previous cultivation seasons, yield quality and quantity losses were reduced due to the reduced crop disorder incidents. The application of agrochemicals and associated expenses of farmers were also significantly reduced, thereby increasing their revenues.

DEDICATION

I dedicate this thesis to my parents and hope this achievement will satisfy the dream both had on me for many years.
Further, I dedicate this thesis to Prof. Athula Ginige for guiding me and being inspirational.
Last but not least, I dedicate this work to all the farmers in rural Sri Lanka.

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Chapter One

Introduction

1.1 Background of the study

1.1.1 Agriculture in Sri Lanka

Agriculture has a long history in relation to human civilization's development and is the key to feeding a magnitude of living beings on earth. It plays an important part in a given economy and is the backbone of a country's economic growth. Sri Lanka is a teardrop-shaped island of 65,000 square kilometres surrounded by the sparkling blue sea (Zubair et al., 2015). With an agreeable climate in terms of ideal temperature and annual rainfall and its fertile soil and widespread freshwater channels such as lakes, rivers, and other freshwater sources, the country is well-known as the pearl of the Indian Ocean.

The country's central hills split Sri Lanka into three main climatic zones and serve as a barrier to the monsoon winds. These climatic zones are wet, intermediate, and dry, and they receive an annual rainfall of 2,500–5,000 mm, 1,750–2,500 mm, and 900–1,750 mm, respectively (Jayawardane & Weerasena, 2000). The climatic zones are divided into 46 agro-ecological zones that are more or less uniform in terms of climatic conditions and soils (Chithranayana & Punyawardena, 2008). A larger number of irrigation schemes are found in the dry zone, and a small number of schemes are found in the other two zones (Jayawardane & Weerasena, 2000). In the wet zone, the rainfall is well distributed throughout the year.

Although the wet zone covers approximately 25% of the land area, it contains around 60% of the country's population, calculated at more than 19 million as of 2007 (World Bank, 2007). The dry zone is characterized by low and highly seasonal rainfall, and it undergoes an extensive dry period for six months, from February to August. In this setting, agriculture is impracticable without irrigation. In the intermediate zone, irrigation water is primarily obtained from anicut schemes, water reservoirs, and lakes (Shand, 2002).

The livelihood of Sri Lankan people has originated with the significant impact of an agricultural history dating back more than 2500 years. Given the ideal ecological conditions, the agricultural sector has always been an influential economic force in Sri Lanka, making notable contributions to the nation's economy, food security, and workforce (Zubair et al., 2015). According to a survey by the World Bank, 23.7% of the total workforce in Sri Lanka was employed in the agricultural sector in 2020 (World Bank, 2020). Moreover, in 2019, the sector contributed to 7.4% of the country's gross domestic product (GDP), as shown in Fig. 1.1. In Sri Lanka, 20.7% of the land is used for agriculture by farmers. Some of the major crops grown by farmers in Sri Lanka are rice, coconut, tea, and rubber, accounting for nearly 80% of the agricultural land use and about 60% of the value-added through local utilization and foreign exports (World Bank, 2007). Moreover, agriculture is the livelihood of the majority of the population in rural areas and plays an essential role in mitigating rural hardship (World Bank, 2007).

Recently, there has been a substantial reduction in the contribution of agricultural production to Sri Lanka's national GDP. As shown in Fig. 1.1, agricultural production accounted for 20% of GDP in 2000 and declined to 7.4% in 2019. Further, employment in agriculture has also significantly decreased, as shown in Fig. 1.2. Overall, such negative outcomes have resulted due to many reasons. The primary reason for this negative growth rate in agricultural production is the prevailing adverse weather conditions such as heavy rainfall, consequent drought, and flooding, which have considerably disrupted the agricultural sector (Nagahage & Dilrukshi, 2012; Shanmuganathan, 2013). Another major reason, which is more specific

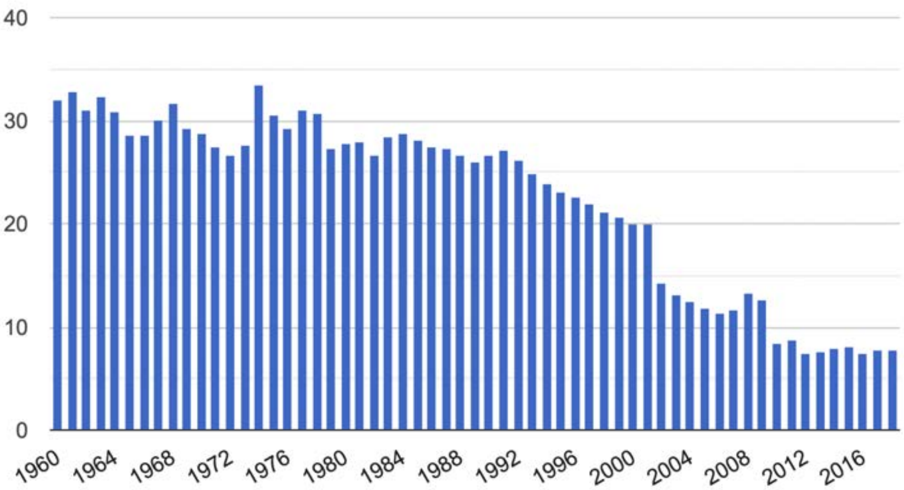


Figure 1.1 GDP share of agriculture in Sri Lanka (theglobaleconomy.com, 2021)

to the negative growth in employment, is the reduced interest of farmers in farming due to the unstable situation in the context of Sri Lankan agriculture and, in turn, affected overall agriculture production. This includes unstable and lack of support available for farmers to access needful information (e.g., recommended farming practices, farm inputs, managing crop losses, to name a few), frequent changes in agricultural policies concerning imports and exports, lower profits, and fluctuations in market prices and production quantities (Aheeyar et al., 2005; Epaarachchi et al., 2002; Perera, 2014).

In the Sri Lankan agriculture context, farmers often get assistance from agricultural extension services to support their day-to-day farming activities. Agricultural extension service is a scheme initiated by the government and plays a role in distributing agricultural knowledge and recommended farming practices to farmers through farmer education (Lamontagne-Godwin et al., 2017; Wanigasundera & Atapattu, 2019). However, the current agricultural extension service in Sri Lanka lacks to provide the necessary support to farmers in a timely manner due to varied reasons (K. Silva & Broekel, 2015). These reasons are explained in section 1.1.2. Moreover, this has created negative impacts on the overall agriculture process in the country and, the effects are already being felt, where farmers have used unreliable sources, such as peer farmers, farm input supply dealers, agrochemical dealers, and sometimes themselves, to seek the support they need (Mengistie et al., 2017). The limitation of such sources is that the information received from each individual is subjective and may lead to bias, resulting in farmers making incorrect decisions and not following recommended farming practices.

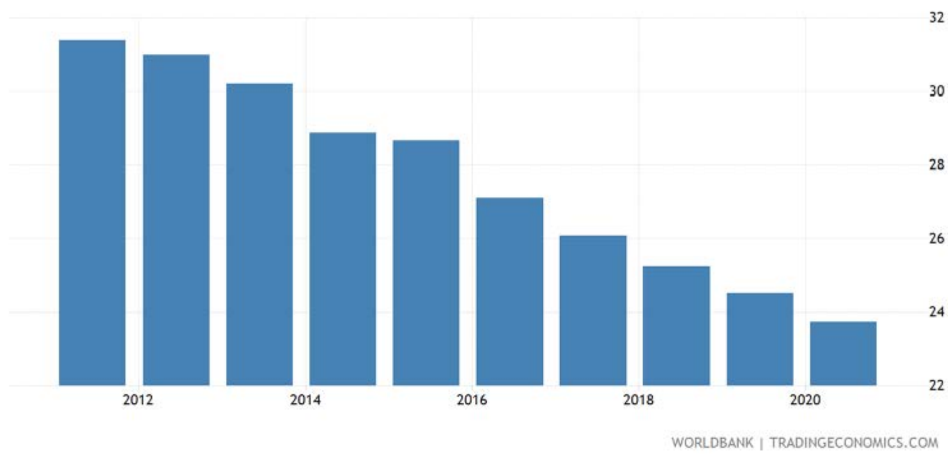


Figure 1.2 Agriculture employment percentage in Sri Lanka (World Bank, 2020)

Such instability in following recommended farming practices, especially when managing crop disorder incidents, has resulted in significant crop losses and decreased yield in terms of both quantity and quality (Baloch & Thapa, 2016). From the farmers' perspective, the selling price of harvest in the market is an important factor in determining the profit (McConnell & Brue, 2002). With the reduced quality of the yield, farmers have to sell their harvest at a reduced price (Lokanathan & Kapugama, 2012), which has a drastic effect on their profit. However, the market's low prices have discouraged both current and future generations to take up farming. For the younger generation, agriculture has become a second choice in terms of career selection because it is aligned with physical exertion and unpredictable profits (World Bank, 2007). Overall, these challenges have resulted in disappointment and dissatisfaction within the farming community, thereby threatening farmer sustainability and, in turn, the country's agriculture production (Henegedara, 2015).

1.1.2 Agricultural extension service

The agricultural extension service has played an important role in strengthening the agriculture sector in many developing countries (Babu et al., 2013). The role of the extension service is to disseminate up-to-date agricultural knowledge to farmers through farmer education. Further, it is the most crucial determinant for boosting farm productivity and maximizing farmer returns. In Sri Lanka, the agricultural extension service had been built up over the decades as an evolutionary process to serve the farming community. In addition, the process of disseminating agricultural knowledge and persuading farmers to follow those in practice is carried out by specialists called agricultural instructors (Senadheera et al., 2013). These agents are assigned to work for agrarian service centres (ASCs), which have been established around the country to provide services to farmers. The duties of agriculture instructors include creating awareness of agri-related innovation among farmers, acting as an intermediary in between agricultural authorities and farmers to disseminate up-to-date agriculture knowledge, providing guidance to farmers, conducting farmer group training, stabilizing new behaviours through directing and reinforcing messages to farmers, and sometimes linking farmers with necessary agricultural inputs (Shah et al., 2013).

Presently, the reach of extension service in most developing countries is limited and faces many challenges (David & Samuel, 2014; Feder et al., 2001). The situation in Sri Lanka is also not an exception. In Sri Lanka, these challenges include frequent changes in government policies and strategies and marketing reforms in the agriculture sector. In addition to non-extension duties performed by agricultural instructors, a lack of qualified agricultural instructors, unwillingness to work in rural areas, serving a large number of farmer groups, and insufficient agricultural instructors to maintain direct contact with farmers, contribute to this situation (K. Silva & Broekel, 2015; Walisinghe et al., 2017). Also, the agriculture extension service in Sri Lanka has not provided a dynamic structure to facilitate effective knowledge dissemination to farming communities. Therefore, farmers' problems are not conveyed effectively to the extension service, and solutions are not effectively passed on to farmers (Jayaratne & Acker, 2003). For example, in Sri Lanka, the extension service has nearly 900 agricultural instructors working to support more than two million farmers (Lamontagne-Godwin et al., 2017). This is an extension officer to farmer proportion of nearly 1:2,220, which means that one extension officer must serve 2,220 farm families; however, given the limited facilities, it is nearly impossible to fulfil the assigned tasks by agricultural instructors, and there is limited time to provide core extension services.

1.1.3 Agricultural crop losses

The state of global food security, which balances the increasing food requirements of the global population, is alarming and requires immediate attention (Ingram, 2011). This inconsistency is not new but has dramatically worsened over the past years, and one major reason for this is crop losses (Dyson, 1999). According to a report by Food and Agriculture Organization (FAO), crop losses refer to the reduction in food mass during the different stages of the food supply chain, such as pre-harvest production, post-harvest handling, agro-processing, distribution, and household consumption (FAO, 2011). Furthermore, the report states that nearly 1.3 billion tons of food produced worldwide for human utilization is consistently wasted and leads to food insecurity and affects people's livelihoods. While quantitative estimations of crop losses have been produced, it is unclear which are the most critical losses in specific supply chains and which solutions are economically, environmentally, and socially feasible. In general, the reasons for crop losses vary around the world, but they mainly depend on the particular circumstances of the geographical area (Savary et al., 2012).

According to a research study, crop losses mostly occur during the early stages of agricultural production (pre-harvest stage) (Kummu et al., 2012; Popp et al., 2012). They occur for many reasons, including extreme climatic variations (e.g., drought, flooding, heavy rainfall), changes in soil conditions, machinery use, wildlife damage, crop disorder incidents (e.g., disease and pest outbreaks), nutrient deficiencies, and damage caused by heavy agrochemical usage (FAO, 2011). Of these, it is found that crop disorder incidents are a significant factor contributing to a large volume of crop losses in the early stage of agricultural production (Oerke, 2005). Moreover, crop losses resulting from crop disorder incidents can be direct or indirect, having short-term or long-term consequences.

A study that investigated the crop losses in Sri Lanka revealed that the overall losses incurred during cultivation, harvest, and post-harvest was accounted for Rs.18 billion annually (Daily News, 2018). The study also revealed that the reasons for this colossal loss include crop damage caused by crop disorder incidents, wild animals, and losses during harvesting. Further, of the overall production in the country, 30% of the crops were damaged due to crop disorder incidents and wildlife damage, and 30% were lost due to misuse of agrochemical effects, post-harvest losses, and unfavourable climate conditions, resulting in only about 40% of crops being utilized for consumption (Daily News, 2018). Due to the damage caused by crop disorders, the usage of agrochemicals has become prevalent among farmers due to its high potential to eliminate and prompt action upon crop disorders (Rahman, 2003). Consequently, farmers in Sri Lanka have started to depend on the heavy use of agrochemicals as the primary way to control crop disorder incidents (Selvarajah & Sivadass, 2007).

1.1.4 Crop disorder identification and management

Disorder incidents can occur in crops at any time, from the pre-planning stage to the post-harvest stage. Globally, an average of 35% of potential crop yields is lost due to pre-harvest crop disorder incidents (Oerke, 2005). Currently, the crop disorder management process that is practised in Sri Lanka consists of three stages: monitoring the field for the presence of any abnormal symptoms, identifying crop disorders if symptoms are present, and employing suitable control measures (Gomez & Thivant, 2017).

In the first stage, farmers perform continuous monitoring in the field to find out the abnormal presence of symptoms in the crops. To do this, farmers walk along predetermined routes or regularly scout through the field (Gomez & Thivant, 2017). Sometimes, farmers use different types of traps to understand the presence of fast-moving insect pests in the field (Van Bruggen et al., 2015). In the second and third stages, farmers identify relevant crop disorders based on the symptoms they identified in the first stage and employ different control measures to manage those. Farmers use various types of sources to assist them in identifying and managing crop disorder incidents. The sources used by farmers to assist their decision-making process can be grouped into reliable and unreliable sources.

Through casual interactions, farmers initially communicate relevant symptoms and crop damages they observed in the field with reliable sources such as agriculture instructors, agricultural researchers, and relevant agriculture authorities. Among these, agricultural instructors are responsible for serving many farming communities, and this situation draws them away from responding in a timely manner to farmers' queries in the event of crop disorder incidents. Moreover, agricultural instructors are reluctant to provide advice verbally without conducting a visual assessment of the symptoms of, or damage to, the plant (Ogutu et al., 2018). Thus, they visit farms to provide advice to farmers after observing the whole scene. It may take several days for them to visit the farms, depending on their workload and engagement with other activities and the distance to the farms.

Crop disorder incidents are time-sensitive problems. Some crop disorders can damage the entire farm field in a day or so. As a result, a delayed response or lack of response from agricultural instructors negatively impacts farmers' ability to take timely remedial action and, consequently, leads them to seek information from unreliable sources or rely on their own experience to acquire the information they need. As discussed earlier, the major problem associated with relying on unreliable sources is that advice received from non-experts may be inaccurate. Thus, this may result in incorrect identification of crop disorders and farmers employing incorrect control measures (Mengistie et al., 2017; Shammi et al., 2020).

In addition, farmers who use such sources are often advised to employ chemical control measures to control crop disorder incidents instead of recommended ones (Knipe, 2016; Selvarajah & Sivadass, 2007). Consequently, the farmers' need, combined with agrochemical dealers' business strategies such as low prices and sales promotion activities, leads farmers to become completely dependent on agrochemicals to manage crop disorders (Knipe, 2016).

In general, crop disorder identification is a complicated process in agriculture with various challenges that requires a more in-depth investigation. To manage crop disorder incidents in the field, accurate identification of crop disorders is crucial. In the first instance, the researcher conducted a thorough study of the crop disorder identification process by continuously interacting with subject experts. Elaborating on the discussions with the subject experts, the researcher conducted a causal analysis to identify different elements involved in the crop disorder identification process and associated relationships between the elements. The resulting causal map is presented in Fig. 1.3. The causal map also helped us visualize an overall picture of the problem domain and assisted in identifying the underpinned challenges. As per the given causal map, a crop becomes prone to different crop disorders due to the influence of causal agents such as fungal, viral, bacterial organisms (collectively called pathogens), animal pests, and other reasons such as chemical toxicity, weeds and mechanical damage (Oerke, 2005). Similarly, crop disorders can be grouped as diseases, pests, nutrient deficiencies, and disorders due to extreme climatic conditions, application of machinery and chemical toxicities. From the identified causal map, it is evident that a given crop disorder manifests different symptoms depending on the growth stage of the crop, crop variety, the development stage of the crop disorder, and where it is located in the crop (Bock et al., 2010).

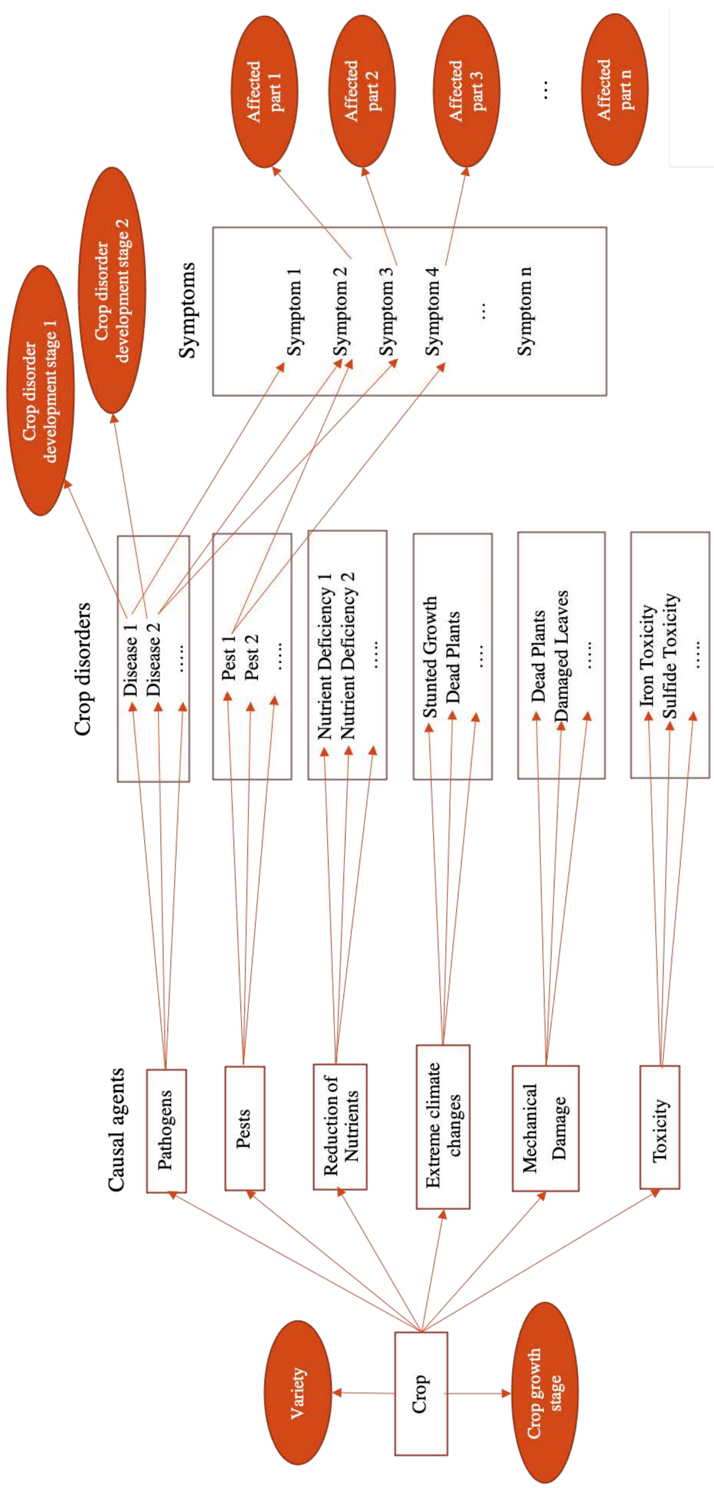


Figure 1.3 Crop - Causal Agents - Crop Disorders - Symptoms Relationship

In addition to the nature of the problem domain identified from the causal map, the following challenges were also identified as part of the study that makes the crop disorder identification a more complex process;

- According to the causal map identified, obtaining symptoms-related observations present in the crops is crucial for the correct identification of crop disorders. In practice, farmers are the main observers who sight such observations in the crops at the first instance. Hence, obtaining information about the exact depiction of such observations from farmers is necessary. On the other hand, uncertainties associated with the field observations may lead to incorrect identification of crop disorders. Furthermore, even with relevant field observations, identifying the right crop disorder is challenging because different crop disorders manifest different symptoms, and the crop disorder has to be identified from larger possibilities of crop disorders (Zhang & Meng, 2011).

- The common appearance of the symptoms manifested by different crop disorders makes the identification even harder (Ahmad et al., 1999). That means, regardless of the causal agents, some crop disorders exhibit common symptoms. This is illustrated in the identified causal map, where Pest 1 exhibits Symptom 2, and Symptom 2 is also common to Disease 2. In the real world, as an example, yellowing of leaves is a common symptom found in many crop disorders and is caused by different causal agents, such as fungal, bacterial, viral, and nutrient deficiency (Shurtleff et al., 1999). Hence, in such cases, the common symptom would not help to identify the right crop disorder due to its common presence among different crop disorders.

- The number of causal agents that can infect a plant and cause crop disorders is usually higher in practice. Therefore, one important challenge to be addressed is the ability of the solution to identify all possible crop disorders specific to a crop.

- Sometimes, multiple crop disorders may manifest concurrently on the plant result in complications in crop disorder identification (Ahmad et al., 1999; Bock et al., 2010). This situation arises because when one causal agent weakens a crop's immune system, different crop disorders can easily infect that crop.

- As identified in the given causal map, in practice, symptoms with respect to a crop disorder may appear on different parts of the crop, such as the flower, leaf, stem, and many others. Also, the symptoms vary according to the crop's growth stage and development stage of the crop disorder. Therefore, crop disorder identification should be intended to identify crop disorders from symptoms that appear on any part of the crop, any growth stage of the crop and the development stage of the crop disorder.

- In some instances, crop disorder identification is carried out based on the scent feature of the symptom (Takayama et al., 2013) and this challenge also needs to be addressed.

- Advising farmers with recommended and time-specific responses about the control measures concerning the crop, human health, and environmental safety aspects is also a challenge. This is detailed in section 1.1.5.

Several attempts have been reported in the literature to provide limited support in identifying crop disorder incidents and, in turn, to help farmers employ recommended control measures. These attempts provided limited support and were not considered as trustworthy solutions mainly due to not addressing the challenges as identified. As discussed, obtaining correct field observations from farmers is the initial and critical step in the crop disorder identification process; accordingly, part of the reported approaches in the literature was mainly based on farmers transmitting field observations as images to laboratories for manual identification by the subject experts (J. Smith et al., 2009; Suen et al., 2014). Such approaches are not effective because the process of crop disorder identification becomes challenging when these images do not depict the actual conditions in the field or, sometimes, time delays in processing a large volume of crop disorder incidents reported by farmers. As an alternative, in some instances, the subject experts visit the farm fields and prescribe the recommended control measures to farmers based on the field conditions (Maraddi et al., 2016). In practice, this is a slow process that might cause delays, thereby hindering farmers' ability to take timely preventive measures. Given this scenario, it is important to develop strategies to identify crop disorder incidents rapidly and reliably. Accordingly, a common approach that was emerged within the research community was to carry out the overall crop disorder identification in two steps:

- step 1: symptom identification
- step 2: crop disorder identification

Here, the output of step 1 was used as the input to step 2 to identify relevant crop disorders. However, the reported approaches in the literature reviewed so far used images that depict the field observations as the primary input to carry out the crop disorder identification process. With the advancements in ICTs, researchers have developed rigorous image processing and machine learning models to rapidly identify crop disorders from the images obtained from the farmers (Chaudhary et al., 2012; Moshou et al., 2011; Pongnumkul et al., 2015; Sannakki & Rajpurohit, 2015). The generic approach used by the researchers in the crop disorder identification process is illustrated in Fig. 1.4. Even with more sophisticated methods, these efforts still pose significant limitations and ambiguities in identifying crop disorder incidents.

A notable limitation identified concerning the symptom identification step of the current approaches is the dynamic capture condition of the images provided by farmers. For example, varied viewing angles and scene configurations compared to the expected settings make symptom identification more difficult in the first step. Also, in the reported approaches, a lack of attention was given to the factors such as the development stage of the crop disorder, the growth stage of the crop, location of the symptoms on the crop, the simultaneous appearance of multiple crop disorders and common symptoms manifested by different crop disorders. This collectively makes crop disorder identification impracticable in the following step (Ahmad et al., 1999; Bock et al., 2009; Pourreza et al., 2015; Pydipati et al., 2006; Zhou et al., 2015). Besides, in the reported studies, the farmers' involvement in crop disorder identification was wholly disregarded. As farmers are the ones who sights symptoms related observations in the field initially, disregarding this aspect and fully relying only on images to identify crop disorders may extensively affect the correctness of the solutions.

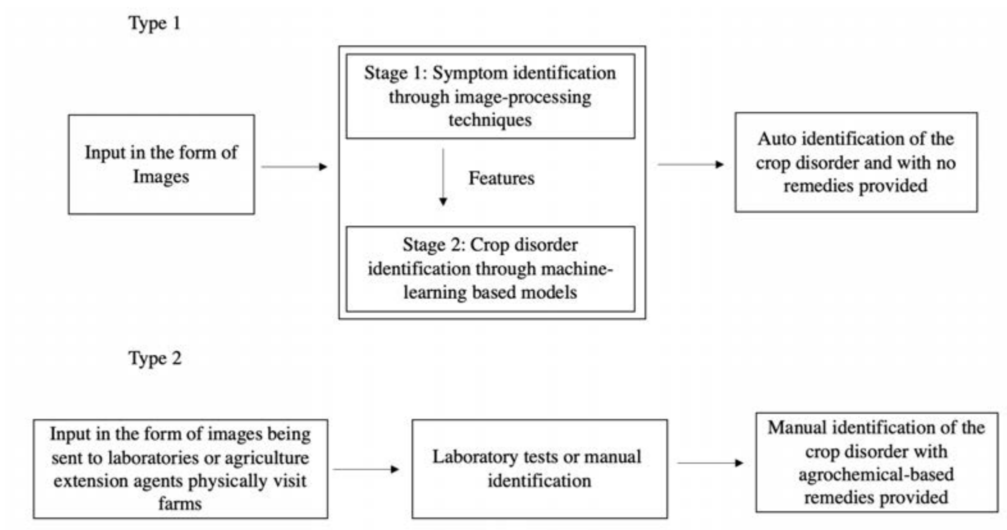


Figure 1.4 Generic crop disorder identification pattern proposed in the literature

After identifying the relevant crop disorder, farmers must employ recommended control measures to eliminate the crop disorder from the field and reduce further crop damage. However, another important limitation linked to current approaches is that, although they attempt to identify crop disorders in the field, they fail to provide recommended control measures as the response back to farmers (illustrated as Type 1 in Fig. 1.4). As a result, farmers do not know how to control crop disorders. A few studies that have attempted to provide control measures to farmers was mainly when agricultural instructors visit the farm (Maraddi et al., 2016; J. Smith et al., 2009). However, such approaches are time-consuming and prevent farmers from taking actions in a timely manner; in addition, the provided recommendations are not environmentally friendly, resulting in further challenges to human health and the environment (illustrated as Type 2 in Fig. 1.4). Furthermore, an overall review of the literature reveals that the reported attempts have concentrated only on one aspect at a time (either Type 1 or Type 2); thus, possible alternatives should be explored to address the underpinned challenges of crop disorder identification as a whole.

1.1.5 Agrochemical usage in Sri Lanka and its effects

The management aspect of crop disorder incidents is mainly based on adapting cultural, mechanical, biological, and chemical control measures. However, before the green revolution period started, farmers did not use any chemical control measures because of the natural tolerance characteristics of conventional crop varieties (Wilson & Tisdell, 2001). Moreover, the use of agrochemicals was sometimes impossible due to additional expenses and the low yield potential of traditional crop varieties. However, as a result of green revolution technologies, the natural tolerance of traditional crop varieties has largely disappeared, resulting in a demand for agrochemicals to control crop disorder incidents. Fig. 1.5 presents the continued growth of agrochemical usage globally. The use of agrochemicals in Sri Lankan agriculture originated in the early 1950s, and the quantities used grew by nearly 110 times between 1970 and 1995 (Wilson, 1999). In addition, farmers in Sri Lanka use stronger agrochemical concentrations in an increased number of applications, and they mix various agrochemicals to improve resistance properties in relation to agrochemicals (Padmajani et al., 2014).

A study that examined a 20-year period of agrochemical usage in upcountry districts in Sri Lanka (i.e., Matale, Nuwara-Eliya, Badulla, and Kandy) revealed that 59% of farmers used more than the prescribed dosage level of agrochemicals in their agriculture activities (Chandrasekara et al., 1985). Another study conducted among the upcountry farmers of Sri Lanka explicated that nearly 45% of farmers used higher agrochemical dosage levels than the prescribed quantity and at a higher frequency to ensure more crop productivity

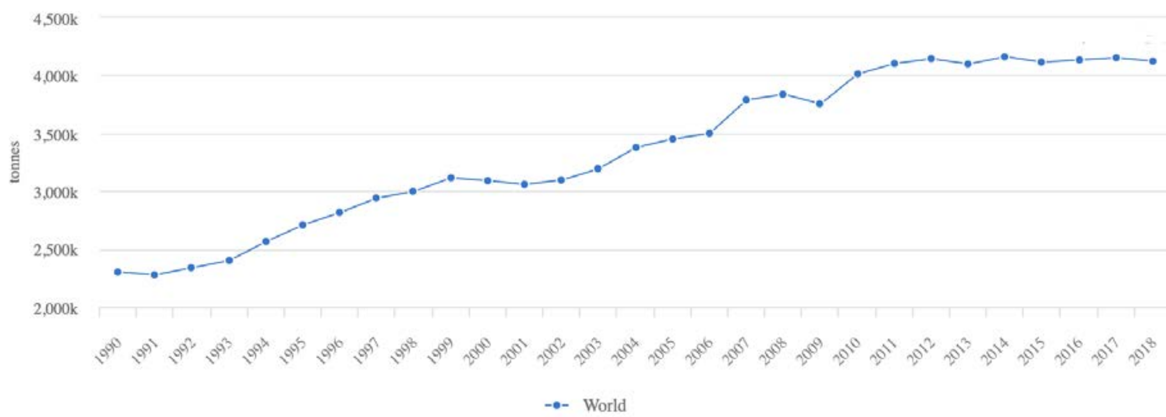


Figure 1.5 Agrochemical usage worlwide (Source: fao.org)

results (Watawala et al., 2010). It was also found that farmers in the Vavuniya district in Sri Lanka applied large amounts of agrochemicals for vegetable cultivation due to the susceptible behaviour of the crops to different crop disorder incidents (Nagenthirarajah & Thiruchelvam, 2008). Moreover, the study revealed that nearly 60% of farmers applied concentrations of agrochemicals that were 40% higher than the prescribed dosage level because they thought they would achieve a higher economic return by minimizing crop damages. Some farmers believed that agrochemicals were less productive and hence overused them, and also as a precaution, farmers engaged in overdosage and frequent agrochemical application even before any crop disorder symptoms arose (Nagenthirarajah & Thiruchelvam, 2008). In recent times, extreme dependency on agrochemicals has imposed significant impacts on the environment, human health, agriculture productivity and income of farmers (Wilson & Tisdell, 2001).

The health effects resulting from the application of agrochemicals form a significant health risk in most developing countries, and this problem shows no indication of decreasing (Maumbe & Swinton, 2003). Various field studies in Sri Lanka have shown that farmers have high morbidity rates due to the heavy usage of agrochemicals, with symptoms including headaches, feelings of being faint, nausea, and diarrhea (Dharmawardene, 1994; Van Der Hoek et al., 1998). In general, the negative effects of agrochemicals can develop in the human body in the short term and the long term basis(Nielsen, 1987). Short-term symptoms, such as rashes and feeling faint, appear shortly after spraying. The delayed health hazards of agrochemical usage include cancer, kidney ailments, and vision problems. For example, a study carried out in Sri Lanka found that farmers using agrochemicals were at a higher risk of chronic renal failure (Valcke et al., 2017). Also, agrochemical poisoning is a major reason that accounts for 60% of the suicide deaths in Sri Lanka (Somasundaram & Rajadurai, 1995).

From an environmental perspective, it has been estimated that more than 50% of agrochemicals used on crops miss their target and fall onto the surface of the soil (Sande et al., 2011). Agrochemicals can easily mix with soil and water, and some chemicals can persist in the soil for many years. They can also be toxic to other living beings, such as birds, fish, beneficial insects, and non-target plants (Selvarajah & Sivadass, 2007). For example, the run-off of agrochemicals into water areas can affect aquatic animals by polluting groundwater and surface water sources. A study carried out in the Nuwara Eliya district of Sri Lanka revealed that milk samples collected from livestock consisted of different chemical components due to the feed for the livestock had traces of agrochemicals (Chaminda et al., 2012).

In Sri Lanka, it has been the long-held practice of farmers to apply agrochemicals in the first appearance of crop disorders due to the fear of potential crop losses, even though it is not required. Unnecessary application of agrochemicals affects the quantity and quality of the harvest, resulting in lower selling price for the harvest (Aktar et al., 2009). Further, the expense related to agrochemicals forms a considerable portion of the farm's budget (Ricker-Gilbert et al., 2008). However, these expenses can be largely minimized through practising integrated pest management (IPM) practices. IPM is an environmentally friendly way of managing crop disorder incidents (Dhawan & Peshin, 2009). IPM uses a combination of different types of control measures to manage crop disorders and to prevent those from occurring. Table 5.7 abstracts different types of IPM-based control measures and the activities associated with each type. This also helps to minimize the demand for agrochemicals as this recommend using agrochemicals as a last resort after trying other control measures

(Flint, 2012). Farmers who employ IPM-based practices in farming are more likely to achieve long-term gains such as increased agricultural productivity, less crop damages, being able to prevent the crops from likely crop disorders in the future and other environmental benefits. In recent times, solutions have been developed, including in Sri Lanka, to enable farmers to access information related to different control methods to manage crop disorders (DOA, 2020; Govi Mithuru, 2020; mKrishi, 2020). Nonetheless, these approaches do not seem popular enough among farmers due to the fact that they do not suggest environmentally friendly remedies, and the information is not accessible in a format they will understand.

Control method	**Activities involved**
Cultural method	Adjust planting location, adjust timing intervals between activities, crop rotation, watering and fertilizing, grow competitive plants, and change cultivation techniques
Physical method	Place barriers and traps, physically remove affected plants, vacuum, heat treatments, and mowing
Biological method	Use of predators, parasites or microbial pathogens, encourage natural enemies by planting specific plants
Chemical method	Use of toxic-chemical substances

Table 1.1 Types of IPM-based control measures

On the other hand, the indirect costs of agrochemical usage also are high as a result of the damage that occurs in relation to agricultural production, such as costs relating to hospitalization, doctor consultations, specific dietary requirements, and hired labour due to the difficulties of farmers working during sick days. According to a study, the estimated hospital-related cost of farmers' susceptibility to agrochemicals in Sri Lanka was, on average, Rs.5,465 annually in 2000, equal to about a month's profit for a farmer (Wilson & Tisdell, 2001). Also, in developing countries, the economic consequence of agrochemicals specific to non-target species has been valued at approximately $8 billion per year (Aktar et al., 2009).

As evident through the above findings, the present situation in Sri Lanka specific to crop disorder management has imposed so many challenges in achieving sustainable economic, health, and environmental development of the country. Thus, developing a crop disorder management process by addressing all the challenges identified will assist farmers to respond to crop disorder incidents more effectively and in a timely manner. This will also help to achieve healthy living conditions of communities, a non-toxic environment, stable income opportunities for farmers, increased agricultural productivity, reduced losses and cost, and many others.

1.2 Research overview

1.2.1 Research aim

The lack of a process to correctly identify crop disorders from field observations and to assist farmers in implementing recommended controls in a timely manner is a major problem in agriculture. Presently, farmers receive the relevant knowledge on this topic in an unorganized manner from pathologists, entomologists, agronomists, and agriculture extension officers, and the issue remains unresolved. In order to come up with an effective process and to organize knowledge for a desired outcome, perspectives and approaches drawn from different disciplines must be incorporated. This kind of problem reflects the nature of multidisciplinary research. In order to mitigate problems in multidisciplinary research, researchers collaborate with other researchers from different disciplines and contribute to the solution of a problem. In response to this problem, a mobile-based artifact was developed that empowers farmers to identify crop disorder incidents instantly and manage them effectively by providing relevant information in context. In addition, a crop disorder search space model was proposed that is composed of mapping between different crop disorders and symptom(s) that provide unique identification characteristics specific to each crop disorder. This model was later converted into a mobile-based artifact, and the information required to perform the search operation in the search space was obtained from farmers through it. This requires collaboration and engagement between experts in the agriculture and ICT domains. This allows for a synthesis of ideas and characteristics from both domains. Further, to distinguish the scope and responsibilities clearly, the main focus of the research in this study was to explore the technology perspective of the solution, for which the necessary knowledge to shape the solution was derived from agricultural experts.

The aim of this research is to develop a process for correctly identifying crop disorders from field observations and, in turn, assist farmers in managing those using recommended control measures while minimizing the use of agrochemicals.

1.2.2 Objectives of study

As per the research aim formulated, this research identifies the following areas that require a more in-depth investigation: symptom identification, crop disorder identification, and providing control measures. Accordingly, a list of objectives was identified as part of this research to meet the research aim.

- This research attempts to create an artifact to obtain symptom-related observations from farmers and attempts to perform the crop disorder identification in an effective manner.
- This research also explores a way to provide recommended control measures to help farmers control crop disorders effectively and on time while minimizing agrochemical usage.
- Finally, this research identifies the effectiveness and impact responses towards the proposed artifact from the farming community.

1.2.3 Significance of study

The findings from this research will enable us to achieve the following significant outcomes.

- The correct identification of crop disorders in a timely manner will help farmers to employ control measures on time to reduce crop damages. This will also minimize the chances of farmers employing incorrect control measures due to misidentifying the problem and relying on unreliable sources.
- Making farmers adhere to the recommended control ways to manage crop disorders will help to reduce the chances of farmers being dependent on agrochemicals, minimize the production cost, and prevent the field from likely crop disorder incidents in the future. Overall this will result in increased agricultural productivity and improved human health and environmental safety.
- A streamlined process of crop disorder identification helps to reduce the workload on the limited number of agriculture instructors and facilitate farmers with timely decision-making. This will also reduce the time delays in agricultural instructors responding to farmer queries and allow the limited number of agricultural instructors to become more effective.
- The behavioural responses of the farming community towards the proposed artifact helps to provide policy directives and recommendations to relevant authorities in promoting and popularising such interventions within farming communities.

1.2.4 Thesis outline

This thesis contains the following chapters. Chapter 2 contains the literature review, which explores the decision support tools used by farmers in the agriculture sector, the recent ICT-based interventions in managing crop disorder incidents and the associated limitations. The gaps identified in the literature are also presented in Chapter 2. Chapter 3 details the research methodology and methods used throughout this research work. Chapter 4 explores the current status of crop disorder management in Sri Lanka, including the challenges identified using a baseline study conducted among the participants identified in Chapter 3. Chapter 5 outlines the design and implementation aspects of the proposed artifact, followed by deployment and evaluation of the artifact. Chapter 6 describes the reflection and learning obtained from iteration 1 of the research study. This will be followed by the refinements proposed to the artifact and an evaluation of the results after deploying the refined artifact. Finally, chapter 7 concludes the thesis with an overall summary of the findings, recommendations, formalization of the work and directions for future work.

Chapter Two

Literature Review

Based on the research objectives defined in section 1.2.2, to enable a deeper dive into specific research areas, this chapter discusses different types of agricultural information required by farmers and the sources from which they obtain this information that is related to symptom identification, crop disorder identification, and obtaining control measures. This is followed by a study of the global trend toward ICTs, and the role of ICTs in agriculture. Next, a comparative study is presented on how ICTs and related advancements have been used to identify crop disorder incidents and how control measures are provided to farmers. The motive of this review is to identify the underpinned limitations with the reported works and examine possible avenues to mitigate them. Finally, a summary of the literature is presented, and this serves as a basis to formulate the research questions.

2.1 Agricultural information needs

Agriculture is a highly knowledge-intensive sector that consists of different types of information, and the use of this information by various agriculture stakeholders, including farmers, helps them achieve better outcomes and improve agriculture productivity (Case, 2003; FAO, 2012). Agricultural knowledge can be categorized as information that is required before planting, during the growing stage, and at the harvesting stage. Information required in the before-planting stage includes farmers choosing the right crop varieties to grow, scheduling crop activities, determining water supply, input cost, the availability of fertilizers or agrochemicals, and soil fertility (P. K. Reddy & Ankaiah, 2005; Tiwari, 2008). During the growing stage, the relevant information relates to climate changes, water requirements, crop disorder management, fertilizer, and agrochemical application is required by farmers (Ratnam et al., 2006). Finally, at the harvesting stage, farmers require information related to storage, market opportunities, financial planning, and market prices (Irivwieri, 2007). To maximize agricultural productivity, farmers should be aware of and follow recommended farming practices throughout the farming life cycle. However, in Sri Lanka, the essential information is not always shared with farmers who can benefit from it due to the limitations of the agriculture extension service. As a result of the limitations, farmers lack access to context-specific agricultural advice, which is not personalized enough to suit their context and are not always satisfactory (Kalusopa, 2005).

Information need on crop disorder management

In the literature on information that is relevant to farming activities, there is a greater emphasis on the topic of crop disorder management (Ekoja, 2004; Rao, 2004; P. K. Reddy & Ankaiah, 2005). Specifically, the crop damages caused by pests, diseases, weeds, and other factors have always been a challenge for those seeking better agricultural productivity (Ruttan, 2002). These harmful organisms can cause significant crop losses in terms of yield quantity and quality. According to a study, crop losses resulting from crop disorders can range from 50% to 80% among crops (Oerke & Dehne, 2004). As discussed in Chapter 1, the occurrence rates of crop disorders progress for various reasons; therefore, high agricultural productivity mainly relies on efficient crop disorder management practices. Therefore, providing information related to recommended management practices is an essential part of any agricultural system to safeguard crops from crop disorders.

In agriculture, managing crop disorder incidents can be carried out by adopting cultural, mechanical, biological, and chemical control measures. However, farmers widely employ chemical control measures as the primary means of managing crop disorders in agriculture production (Cooper & Dobson, 2007). Despite the advantages of chemical control measures in controlling crop disorders, they can also have adverse effects (Pimentel et al., 2005). Crop disorder problems are often complicated, requiring precise and reliable information to manage them. This complexity is further compounded because farmers have limited or inadequate knowledge about the problem and the inherent control measures to address it. Therefore, when agrochemicals are selected as the preferred control method type, farmers must use them carefully to ensure efficiency as well as individual and environmental protection, including legal compliance. This aspect is important because careless handling of agrochemicals by farmers due to intentional and negligent behaviour and lack of training may adversely affect the agriculture production, environment, and human health safety (Salameh et al., 2004).

In most cases, decisions on employing effective crop disorder management practices are subjective and depend on farmers' socio-economic profiles, available knowledge, perceptions, and objectives (Ajayi, 2000; Atreya, 2007). Hence, farmers must be aware of available crop disorder management practices, especially IPM-based practices, including conceptual and technical aspects and how to employ those. Often, farmers receive information about control measures but are not able to take full advantage of those measures because the given information is not in a form they can understand and there may be delays in receiving it (Mbah et al., 2010). A study on the information needs of tribal farmers in Arunachal Pradesh in India found that most farmers require information related to crop disorder management and relevant control measures to manage crop disorder incidents (Raj, 2008). Another study conducted among paddy farmers in Nigeria disclosed that 89.9% of the farmers require information related to crop disorder management to control pre-harvest crop losses (Tologbonse et al., 2008). A survey of farmers in Karaj, Iran, reported that farmers have a varied understanding of crop losses and control measure practices and require constant input and training to manage these facets (Hashemi et al., 2009). A similar study that assessed farmers' knowledge of agrochemicals' usage and handling found that the farmers have limited knowledge regarding crop losses, reasons for crop losses, and the selection, use, and overall handling of agrochemicals (Rijal et al., 2018). In summary, these studies emphasize the importance of effectively providing relevant support to farmers in managing crop disorder incidents.

2.2 Global trends in ICTs

Information and communication technologies (ICTs) enable users to access, manipulate, store and transmit information (Unwin & Unwin, 2009). Although there is no standard definition of ICTs, the term generally refers to the devices, networking components, applications, and systems that permit people to communicate in the digital world. Thus, the concept of ICTs is somewhat related to information technology (IT); however, it concentrates mostly on communication technologies such as the internet, Bluetooth, wireless networks, mobile phones, and other transmission mediums (Ratheeswari, 2018).

Several scientific studies advocate that ICTs can enable more sustainable transitions in sectors such as power, transportation, manufacturing, agriculture and many others (Hilty et al., 2011). A study carried out by the World Bank claims that ICTs in the 1960s significantly helped economic production and distribution, public service delivery, and government administration of many countries (World Bank, 2006). In the 1980s, information was identified as an essential part of many industries, resources, and labour. Further, in the 1990s, ICTs became crucial as a result of globalization and increased information needs combined with technological development and demand. The study also emphasized the importance of ICTs globally to provide essential information for economic improvement, contribute to global integration, and enhance the livelihood of people. Over the past decades, experience has shown that ICTs are a requirement for strengthening information societies (UNCTAD, 2019). In recent times, countries have established new protocols to increase the application of ICTs to satisfy people's needs and economic and social development. When tailored to these needs, ICTs can boost the economy's development growth nationally and globally (UNCTAD, 2019).

2.2.1 Role of ICTs

In recent times, the world has faced many challenges in achieving sustainable economic, social, and environmental development, resulting in significant consequences worldwide (Van der Voorn & Popov, 2013). As an example, presently, more than one billion people in the world live in extreme poverty, a lack of access to food and healthcare facilities, and income inequality (Giovannucci et al., 2012). Attaining sustainable development requires people to perform global actions towards achieving economic, social, and environmental growth. Based on this, the United Nations has defined 17 sustainable development goals (SDGs) to achieve a more reliable and sustainable future for everyone (United Nations, 2019). According to a research study, the SDGs provide the means to end various global challenges, which can be achieved through the potential use of ICTs (Jones et al., 2017). Moreover, ICTs can help to build synergies among people and societies and have enormous potential to scale and help countries achieve constant development while contributing to the economy (World Bank, 2006).

From an economic perspective, ICTs present an opportunity for countries to address the digital divide and overcome hardships while achieving stable economic development (Bello & Aderbigbe, 2014). In recent times, almost all countries have witnessed the application of ICTs in multiple sectors such as agriculture, healthcare, transport, mining, construction, and many others, which have significantly contributed to the national GDP (Bello & Aderbigbe, 2014). Furthermore, a research study states that ICTs are essential for the sustainable development of any country, particularly developing countries, and are a critical factor in promoting SDGs (Crede & Mansell, 1998). Although the SDGs do not explicitly refer to ICTs, it has been shown that ICTs can substantially accelerate a nation's development progress, bridge digital gaps, and construct inclusive and knowledge-based economies.

As proof of the above claim, a comparison between ICTs and the SDGs, as shown in Fig. 2.1, reveals a strong correlation between them, suggesting that ICTs enable countries to fast-track their progress on the SDGs (Huawei, 2018). Different SDGs such as quality education, gender equality, good health and well-being, industry innovation, sustainable cities, and clean energy were considered as the benchmark indicators in the study. Most countries at the top of the benchmark are European countries, which is relatively unsurprising, given that they lead in both ICTs and sustainable development progression. Further, most countries scored evenly on some of the SDGs, which the application of ICTs can positively influence.

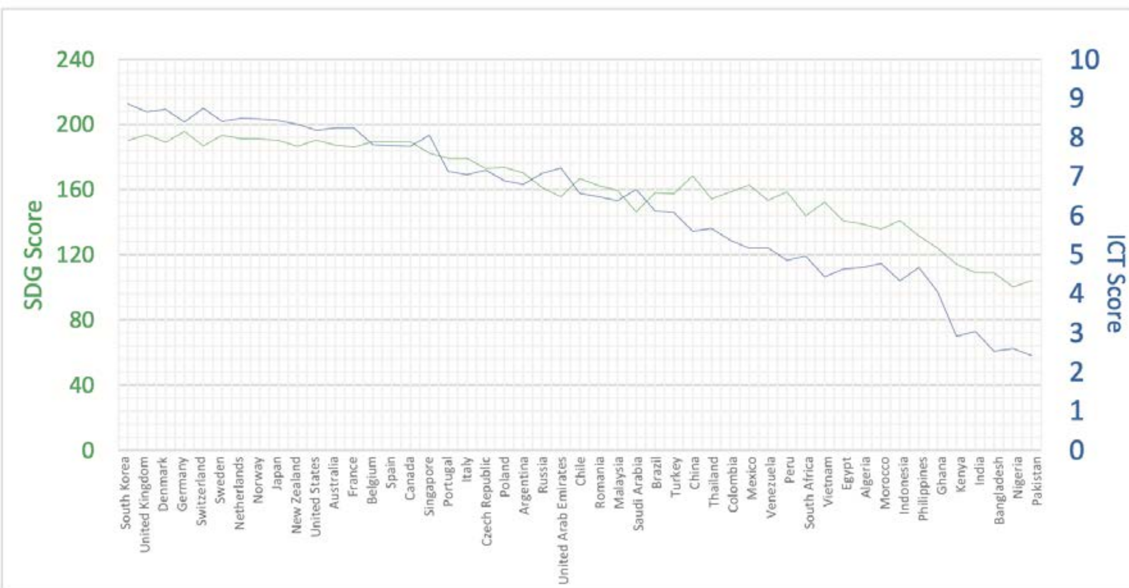


Figure 2.1 SDG scores and ICT scores by country (Source: huawei.com, Accelerating SDGs through ICTs)

2.2.2 Mobile technology

The use of mobile technology has significantly increased over the past decades (Wilmer et al., 2017). Low cost and mobility are the main driving forces behind the rapid growth in the number of mobile subscribers (Qiang et al., 2012). According to the International Telecommunication Union (ITU), mobile subscriptions have increased steadily, while fixed telephone subscriptions have declined (ITU, 2019). This is illustrated in Fig. 2.2. Further, mobile broadband subscriptions continue with an 18% year-on-year growth and continue to grow strongly (ITU, 2019). Recently, the mobile market evolved from phones with basic features to smartphone devices (Wilmer et al., 2017). As a result of the drastic evolution of mobiles, their prices started to decrease in the market rapidly, and they have become affordable in developing markets. The lower cost of mobile phones has enabled even the poorest individuals to own one (Rashid & Elder, 2009).

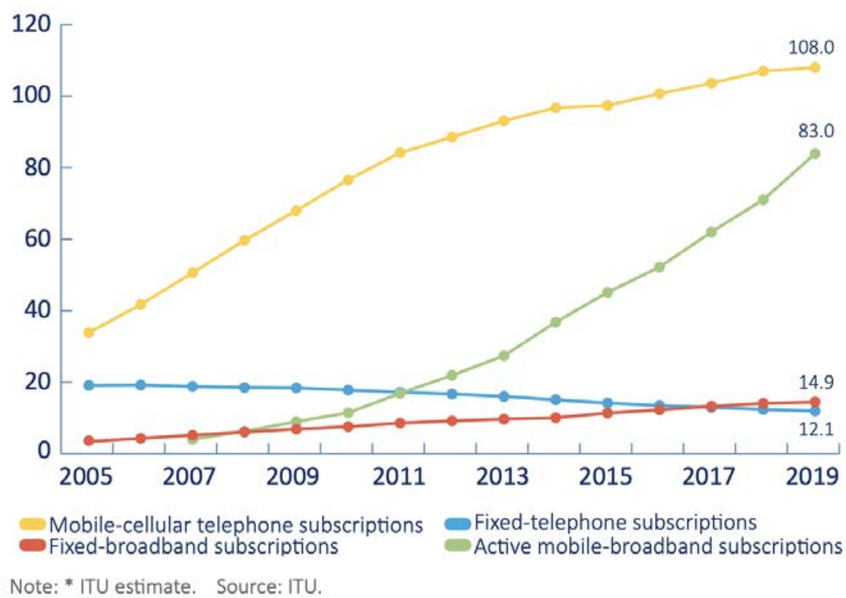


Figure 2.2 Mobile-cellular subscriptions (ITU)

In recent decades, the combination of advancements in ICTs and constant growth in smartphone usage has enabled people to use the internet at any time and any place. According to a report by ITU, the number of people using the internet globally increased from 17% to 51% between 2005 and 2019 (ITU, 2020). The report also stated that, by 2019, around four billion people would be using the internet globally. Most significantly, between 2005 and 2019, the number of internet users increased by 35% in total worldwide (ITU, 2020). In addition, the number of digital devices connected to the internet now exceeds the world's population (Evans, 2011). Growth in smartphone and internet usage has opened up new possibilities by enabling people to access and share information without being limited by time and location (Fernández-Ardèvol, 2011). Moreover, as smartphones continue to become resource-rich devices, they can support applications in different domains such as health, environment, education, agriculture, transport and many others (FAO, 2017).

Smartphones have sensors embedded in them, such as accelerometers, gyroscopes, cameras, and microphones to auto-detect changes in the environment (Mardenfeld et al., 2010). These multi-purpose sensors enable users to sense, create, and share various types of information. In environmental monitoring, smartphones are mainly being used to ensure environmental safety and monitor air pollution. For example, the authors in a study developed a mobile application that allows users to generate customized environmental effect reports (Mun et al., 2009). This work aimed to assess the environmental observations of people regarding climate changes and noise tracks. Likewise, in another study, a mobile application was developed to aggregate information about road diesel traces to explore communities exposure to air pollution (Goldman et al., 2009).

In social network monitoring, applications such as Facebook, Twitter, and Instagram are used as communication platforms to interact with people and share information within communities. These information updates that are shared in the social media platforms can be considered as alerts that describe something that is going on (Kaplan & Haenlein, 2012). In this case, such social media platforms could be used as an emergency notification tool. For example, the authors in a study proposed a way of detecting ongoing community trends based on social media posts posted by people (Liu et al., 2011). Likewise, a machine learning-based model was proposed in a study to predict earthquake occurrences by analyzing user-generated data in social media applications (Hidalgo Mazzei et al., 2020). In another study, the authors proposed an approach of detecting earthquake incidents based on Twitter messages posted by people using smartphones (Sakaki et al., 2010a).

In the healthcare domain, several mobile applications are being used to monitor people's heart rate, blood pressure, and glucose level and evaluate people's health conditions (Khan et al., 2013). For example, the DietSense is a mobile application developed to help people maintain their weight by allowing them to report their food intake information and, in return, receive feedback from medical experts (S. Reddy et al., 2007). HealthAware is another mobile application that helps people improve their health conditions through people-centric feedback (Gao et al., 2009). Furthermore, smartphone applications are also widely in the transportation sector, where many geographic information systems (GIS)-based applications were developed to provide travel-related information to users, e.g., Google Maps (Jovanovic & Njegus, 2008). Moreover, several applications have been developed to monitor road conditions such as road quality and driving behaviours of users (Higuchi et al., 2015). Overall, the above examples suggest the wider applicability of mobile phones in different domains and help people to satisfy their needs in different ways.

2.3 Role of ICTs in agriculture

With the potential of ICTs, traditional agriculture can be reformed to improve agricultural productivity and sustainability. To serve this purpose, the large volume of available agricultural knowledge can be effectively analyzed, structured, and disseminated to farmers to improve their agriculture stability (Ratnam et al., 2006). Further, with the advancement in ICTs, it is also possible to generate locality-based personalized advice for farmers depending on their context. In recent times, the role of ICTs in supporting agricultural systems has been extensively investigated by researchers, non-governmental organizations (NGOs), and government agencies, and it has been shown to play a vital role in effectively transferring the required knowledge to the farming community (Jain et al., 2010).

Several studies carried out in rural areas in developing countries have revealed that the application of ICTs within the agricultural community has significantly increased over the past years (Eden & Kalusopa, 2005; Mwakaje, 2010). For example, a study conducted among the rural farmers of Malaysia found that farmers frequently use ICTs and perceive them as useful tools to obtain agriculture-related information (Shah et al., 2013). A survey reported in a study revealed that ICTs play a vital role in encouraging rural farming communities to adopt sophisticated farming practices (Al-Hassan et al., 2013). Similarly, a survey initiated in Benin found that information delivered through ICT-based tools is more effective than conventional face-to-face discussions conducted by local NGOs and reaches farmers faster (Zossou et al., 2009). Specifically, in Sri Lanka, it has been reported that farmers use mobile phones for their day-to-day needs on their farms, despite their limited knowledge of how to use mobile phones (Subashini & Fernando, 2017). Similarly, the application of ICTs in agriculture extension service to transmit agricultural knowledge to farmers have also shown positive outcomes (Meena et al., 2012). The different types of ICT-based tools and their usage in the agriculture context are presented below:

Telephone and mobile phones

Recently, telephone and mobile technologies have grown as the fundamental communication base helping farmers obtain agriculture-related information (Mangstl, 2008). These communication technologies have numerous benefits, such as spontaneous transfer of information, portability, and a wide range of coverage to support farmers.

As a few examples, in the African region, the mobile phone was one of the prominent ICT-based tools used by farmers to obtain agriculture-related information (Munyua et al., 2009). Similarly, in another study, the authors found that agricultural mobile applications are considered as a robust ICT tool to strengthen agricultural productivity (Mangstl, 2008). In terms of the application of mobile technology in agriculture, the researchers have developed a notification system to inform farmers with short messages to convey farming-related information, such as weather, irrigation, and handling of agrochemicals (Jensen & Iver, 2003). Moreover, in Kenya, farmers receive voicemails that contain market-related information such as market demand, logistics, and price (Munyua et al., 2009). Some studies have reported that farmers share field-level observations as images to relevant people using mobile phones, especially when there is a crop disorder incident (Prasad et al., 2014). This method of communicating and delivering information has eliminated the need for subject experts to visit farm fields physically.

Television/radio

Television or radio is another method used to disseminate agriculture-related information to farmers. This way of delivering information works well for farmers because of the ease of understanding the information provided, especially with visual and animated material. Over the years, many researchers have pointed out the broad applicability of television and radio within the farming community. For example, a study carried out among farmers in Malaysia reported that television and radio are widely used ICT-based tools in disseminating agriculture-related information (Hassan et al., 2008). According to another study, community radios that are used to broadcast information are popular in several farming communities (Adamides & Stylianou, 2018). With the popularity of radio broadcasts, radio usage has significantly improved rural agriculture productivity (Hassan et al., 2008).

Similarly, information related to general agricultural problems and corresponding solutions has been disseminated in Zambia through radio (Luczynska & Gaudi, 2005). The authors found that delivering remedies to general agriculture-related problems through the radio has helped farmers in many ways. According to farmers in Bolivia, the use of the television or radio to report the prices of agricultural produce in the local market is another example of the successful application of ICTs (Blommestein et al., 2006).

Other technologies

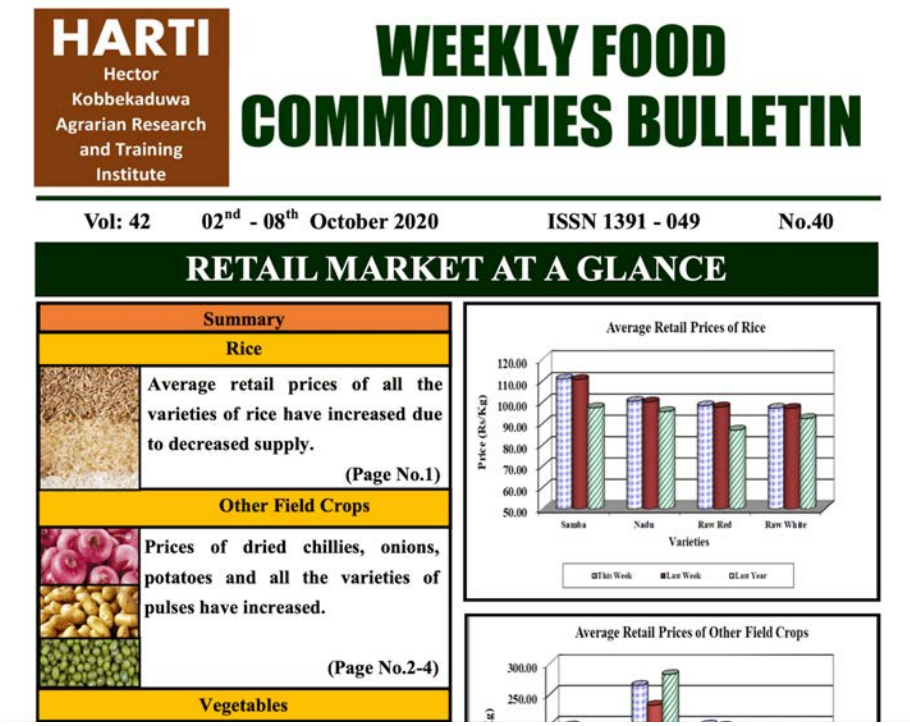
In addition to the aforementioned technologies, other types of ICT tools have been used to deliver agriculture-related information. For example, radio frequency identification devices have been used to capture livestock data (Munyua et al., 2009). Likewise, Geographic Information System (GIS) is a widely used technology in the agriculture sector used to map geographical land digitally. In agriculture, the geodetic data obtained through the GIS can be used to analyze soil conditions better. For example, a project based on a GIS application was deployed to collect information about the soil conditions of 70 villages in the Warana area in India (Tiwari, 2008). Likewise, agricultural activities involving robotics exhibit a high degree of technology and can perform autonomous tasks in recent times. According to a study, an agricultural robot was developed to perform harvesting, weeding, followed by seeding activities in the field (Fountas et al., 2020). The development of agricultural field robots has contributed to the increased efficiency of farming operations, and the attempts to develop agricultural field robots can be seen in many studies (Hameed, 2014; Tillett, 1991). Further, a study was initiated to provide agriculture-related information for farmers in the rural areas of Ethiopia through mobile cinemas (Irivwieri, 2007). This study has shown that this way of knowledge transfer is recommended to stimulate farmers' self-learning capabilities. The above examples show that ICTs have significantly contributed to filling the gap in the agriculture extension service by providing required agriculture knowledge to farmers. Hence, the effective use of ICTs in the agricultural system can lead to improved agricultural productivity.

2.3.1 ICTs and tools used in Sri Lankan agriculture context

In Sri Lanka, the Department of Agriculture (DOA) is the largest government agency that aims to achieve sustainable agriculture production in the country by providing varied services to farmers and other stakeholders. These services include disseminating agricultural knowledge to all stakeholders, conducting awareness sessions for farmers, providing subsidiaries for a reasonable price, and setting policies and controls. In recent times, the DOA has launched many ICT-based initiatives to disseminate agricultural knowledge among farming communities in Sri Lanka. For example, the Govi Gnana is a system deployed in Dambulla, a district of Sri Lanka, to disseminate information to agriculture stakeholders regarding the price of agricultural produce to minimize market price fluctuations, thereby helping farmers sell their harvest at a reasonable price (H. D. Silva & Ratnadiwakara, 2008). This has resulted in increased transparency across the market by displaying the best selling price and limiting personal negotiations; hence, traders have been challenged by the displayed prices.

The official website of the DOA is a comprehensive tool that provides agriculture-related information to the public, including farmers (DOA, 2020). It contains information regarding crops and crop varieties, crop characteristics, fertilizer applicability, nursery management, field-establishment methods and crop disorder management. However, the information on the website is not in a form that is personalized to farmers to assist them in prompt decision-making. Further, some of the information on the website has not been updated frequently and thus does not provide up-to-date information. Wikigoviya is another web-based e-learning solution that is designed to facilitate discussions between farmers and other agriculture stakeholders through audio and video broadcast channels (Pemarathna, 2018). Similarly, the Hector Kobbakaduwa Agrarian Research and Technology Institute (HARTI), a research institute in Sri Lanka, is engaged in producing market information for farmers, traders, and policy-makers (HARTI, 2020), and making the information available on its website, as shown in Fig. 2.3.

In relation to mobile applications, an application named Dialog Tradenet was developed in Sri Lanka to provide market-related information, such as the prices of agricultural produce to farmers. It also serves as a platform to connect sellers and buyers (Dialog, 2010). Likewise, 6666 Agri Price Information Index is an initiative developed in Sri Lanka to provide market-related information to farmers through text messages (Agri-Index, 2020). Govipola is another mobile-based agricultural trading platform that was developed to give farmers, buyers, and sellers access to market prices (Govipola, 2020). This system aims to build a digital index, similar to the stock exchange, to show market trends. Similarly, Govi Mithuru is a system that sends voice messages to farmers with timely advice regarding crop management practices (Govi Mithuru, 2020). However, even though several attempts have been made to provide relevant information to farmers, the level of awareness and use of such technologies remained relatively low among farming communities. This is mainly because the provided information was not personalized enough to suit the farmers' needs and the difficulties in interpreting the given information and acting on them in practice.


HARTI
Hector Kobbekaduwa Agrarian Research and Training Institute

WEEKLY FOOD COMMODITIES BULLETIN

Vol: 42 02nd - 08th October 2020 ISSN 1391 - 049 No.40

RETAIL MARKET AT A GLANCE

Summary

Rice

Average retail prices of all the varieties of rice have increased due to decreased supply.

(Page No.1)

Other Field Crops

Prices of dried chillies, onions, potatoes and all the varieties of pulses have increased.

(Page No.2-4)

Vegetables

Figure 2.3 Example of market information published by HARTI

2.4 ICTs and tools used in crop disorder management

With the result of the advancements in ICTs, several attempts have been reported in the literature to provide limited support in identifying crop disorder incidents and, in turn, to help farmers employ recommended control measures in a timely manner. This literature review seeks to determine how ICTs have assisted in identifying crop disorders, primarily in the form of gathering information about symptom-related observations in the field, identifying crop disorders from the identified observations in the field, and delivering remedial measures to farmers. As already discussed in Chapter 1, the reported approaches in the literature reviewed so far used images that depict the field observations as the primary input to carry out the overall crop disorder identification process. Moreover, this process happens in two steps as presented in Table 2.1.

Study	**Input used**	**Problem**	**Symptom identification**	**Disorder identification**
(Sannakki & Rajpurohit, 2015)	Images	Pomegranate diseases (Bacterial Blight and Wilt Complex)	SVM-based classifier to recognize the symptoms from the images using the colour and texture of the affected area on leaves.	A back propagation-based neural network was developed to identify different types of pomegranate diseases from the identified symptoms.
(Chaudhary et al., 2012)	Images	Spot based diseases on leaves	Image processing-based colour transform approach was used to highlight disease spots on monocot and dicot plant leaves.	Disease spots were classified based on their shapes by applying an image threshold technique called OTSU threshold.
(Moshou et al., 2011)	Images	Fungal diseases in arable crops	A remote sensing system was developed and carried by tractors or robots to capture images. Hyperspectral reflection and multiple spectral imaging techniques were used to highlight symptoms.	A neural network-based model was developed to predict the presence of diseases or plant stresses from the collected images.

Study	Input used	Problem	Symptom identification	Disorder identification
(Sunny & Gandhi, 2018)	Images	Lemon citrus canker disease	A k-means clustering method was used to segment the region of concern, and a grey-level co-occurrence matrix was used to decide on the features.	An SVM-based classifier was used to detect images with canker leaf disease.
(Boissard et al., 2008)	Images	Whitefly detection	Image pre-processing techniques such as smoothing and colour transformation were used to highlight the symptoms.	A machine learning-based classifier was developed to classify the images to identify the presence of whitefly.
(Al-Tarawneh, 2013)	Images	Olive leaf spot disease	Image pre-processing techniques such as smoothing and colour transformation were used to highlight the symptoms.	Fuzzy c-mean clustering and k-means clustering were used in the region of interest in the images to determine the defect and the classification of the detected disease.

Table 2.1 Approaches reported in the literature to identify crop disorders from images

Upon reviewing the existing approaches, it is found that various image processing techniques such as smoothing, color transformation, and segmentation of images were used to identify symptoms from the images provided by the farmers. Similarly, machine learning-based models were developed to identify crop disorders based on the symptoms identified in the previous step. However, it is also revealed that these approaches have focused on identifying a specific crop disorder or a subset of crop disorders instead of all possibilities linked to a crop (Pydipati et al., 2006). In practice, identifying a limited number of crop disorders is inadequate because crop disorder occurrences in a crop are relatively high, and different crops can exhibit different crop disorders (Barbedo, 2016). Consequently, it is difficult to use these approaches to identify all possible crop disorders specific to a crop(s) concerning the effort required to make these approaches work in field conditions.

Moreover, the crop disorders manifest different symptoms depending on the growth stages of the crop, the development stages of the crop disorder, and where it is located on the plant; however, the existing attempts have not taken such factors into their consideration and focused on identifying crop disorders only specific to limited cases. From a technical perspective, this requires a large collection of image samples to identify crop disorders for all possibilities and collecting image samples concerning the above factors is difficult in terms of effort and cost required (Singh & Misra, 2017). Another important limitation identified is that such image processing techniques and machine learning-based models become obsolesces when dealing with common symptoms manifested by different crop disorders or the appearance of concurrent crop disorders at the same time. Similarly, identifying crop disorders based on the scent feature of the symptoms is also not feasible with the current techniques. One example is given in Fig. 2.4, with a coffee leaf that is affected by concurrent crop disorders at the same time. The authors in a study observed that the symptoms used to identify different crop disorders in soybean seeds look very similar, and their model could not distinguish them (Recht et al., 2018). From the approaches presented in Table 2.1, it is not evident whether these aspects have been considered in the reported solutions.

From an external point of view, identifying crop disorders using images has several challenges in terms of the accuracy of the identification. In general, an image processing technique can be defined as manipulating the inherently multidimensional signals such as images or video sequences (Huang & Aizawa, 1993; Koumpouros et al., 2004). The activities involved in image processing include transmission, enhancement, restoration, and recognition. However, many challenges associated with these activities remain unresolved. In enhancing an image, one aims to process an image to improve its quality due to many possible degradations

Figure 2.4 Coffee leaf containing symptoms of both rust and Cercospora leaf spot, Source - (Barbedo, 2016)

such as low contrast, noisy behaviour and is blurred. Over time, many algorithms have been proposed by researchers to eliminate these degradations. However, the major challenge is to eliminate degradations without damaging the multidimensional signals (Huang & Aizawa, 1993). This situation becomes even worse when the image is severely degraded. For example, noise-reduction algorithms are typically used when smoothing an image, but this can also blur the edges of the image.

Another limitation associated with the approaches reported in the literature is the difficulties in making them operate under different practical settings. For example, a model is currently developed, trained, and evaluated on a dataset that is divided into training and validation datasets. Therefore, the training and validation datasets will have the same characteristics, as both are sampled from the same dataset with common imaging conditions. However, in practice, the actual images may appear different from those used in the training and validation stages. For example, the actual image may vary in angles, zoom level, light conditions, scales, content configurations, and camera settings instead of the configurations used while developing the model. A research study showed that the difference in the properties of a dataset would significantly reduce the accuracy of image recognition algorithms (Recht et al., 2018). Thus, even with the use of more sophisticated techniques, image processing techniques still cannot be used in many situations and are error-prone to many factors, as mentioned.

Besides, in the reported studies, the farmers' abilities were wholly disregarded in terms of their experience. Despite field observations being the crucial step in the crop disorder identification process, and since the farmer is the one who observes such observations in the field initially, disregarding this aspect and relying solely on images in the process may extensively impact the accuracy of the solutions. This is mainly due to the challenges associated with the problem domain and the practical limitations of image processing-based techniques, which in turn affects crop disorder identification. Henceforth, there is a need to figure out an effective approach to identifying crop disorder incidents from field observations by addressing the underpinned challenges.

After the correct identification of a crop disorder, the relevant control measures should be given to farmers to enable them to manage crop disorders from further crop damage. However, the findings from the literature show that farmers required more time-specific response for prompt decision-making and the information they received were not specific enough to meet their needs. Table 2.2 presents a few of such approaches proposed in the literature to provide information related to control measures. These approaches have used various communication channels such as websites, mobile devices, and printed forms to assist farmers in accessing relevant information. It appears however that these works fail to adequately present the relevant control measures due to focusing exclusively on chemical control measures and not presenting alternatives such as cultural, biological, and mechanical solutions. This will result in difficulties in understanding and employing those in practice and motivate farmers to adhere to chemical-based control measures and not be exposed to other recommended strategies.

Study	**Delivery method**	**Remarks**
(DOA, 2020)	Information is published on a website.	Farmers have minimal knowledge on using computers to access any content through websites. On the other hand, the provided content is not appropriately structured, and the farmer has to go through the entire content to extract necessary information resulting in time delays.
(Govi Mithuru, 2020)	Information is delivered through a mobile-based application.	Only chemical control measures were considered as opposed to IPM-based control measures.
(mKrishi, 2020)	Information is delivered through a mobile-based application.	Only chemical control measures were considered as opposed to IPM-based control measures.
(Wu & Chang, 2013)	Information is delivered through a mobile-based application.	Only chemical control measures were considered as opposed to IPM-based control measures.
(Maraddi et al., 2016)	Information is delivered through printed forms.	Only chemical control measures were considered as opposed to IPM-based control measures. To deliver the required information, the subject experts have to manually visit the farm and provide advice resulting in a delayed response.

Table 2.2 Techniques proposed in the literature to deliver remedial actions

2.5 Literature summary

Correct identification of crop disorders based on field observations and managing them using timely and recommended control measures are critical drivers for reducing crop losses and preserving the environment and human health. To find the current state-of-the-art, a thorough literature review has been carried out to better understand the reported approaches that are focused on identifying crop disorders from field observations and providing relevant control measures.

With advancements in ICTs, several attempts have been reported in the literature to address this problem; however, they only provide limited support for identifying crop disorder incidents. Most use automated approaches to identify crop disorders based on the images being sent by the farmers. However, such approaches fail when these images do not depict the actual conditions in the field. Moreover, such solutions tend to identify only a specific type of crop disorder, and they cannot identify a broader group of problems due to practical limitations. These include the presence of partial symptoms in crops, the presence of common symptoms across different crop disorders, the appearance of symptoms in different parts of the plant, and variations in image capture conditions.

In addition, various circumstances may also affect the characteristics of the images sent by farmers, making it difficult for systems to perform meaningful identification. Ideally, the images should be captured under the same conditions as those used to train such systems. However, this can only be accomplished under more controlled conditions, similar to a laboratory, but not in practice. Another crucial observation identified was that the farmers' involvement in the process of crop disorder identification was wholly disregarded. Farmers are the ones who sight the symptoms-related observations in the field initially; hence, disregarding this aspect and fully relying only on images to identify crop disorders may extensively affect the correctness of the solutions. Overall, this hinders timely identification of crop disorders and farmers' ability to take relevant control measures.

As evident, the overall results obtained from the reported works in the literature are inconclusive, with several limitations. Given this scenario, these challenges and limitations must be addressed when developing an intervention to identify crop disorder incidents from field observations.

Chapter Three

Research Methodology

3.1 Research Plan

The research process is an outline of the steps that the researcher plans to undertake to achieve the research aim (Saunders et al., 2019). The researchers also defined the term research as a systematic process that includes defining, undertaking, and describing an investigation in relation to a research problem (Maylor & Blackmon, 2005). Similarly, investigating and exploring different research methodologies and selecting the most suitable one adds value to research in many ways (Thomas & Nelson, 1996). Notably, it makes researchers aware of certain do's and don'ts in research and the different techniques that can be used to collect and analyze data and evaluate the results. As per the research aim formulated in Chapter 1, the primary objective of this research is to develop an ICT-based intervention to provide farmers with an effective way of managing crop disorder incidents. Hence, it is essential to identify a suitable research methodology to guide researchers' response to the identified research problem by choosing the correct research methods, materials, tools, and techniques. The identified characteristics of the research problem are as follows:

- In general, the nature of crop disorder identification is a complicated research problem leading to more detailed sub-problems, each with varied challenges, resulting in requirements evolved iteratively. Finding a solution to this problem also requires the involvement of subject matter experts in the agriculture sector, such as entomologists, pathologists, socio-economists, and agriculture instructors. Thus, this research can be considered multi-disciplinary research that requires a collaborative effort. To better understand the problem area and to develop ways to address the problem, the researcher must continuously interact with the subject experts, including the end-users.

- As evident through the literature study, designing an IT artifact would be a possible option to strengthen the information flow in the crop disorder management process. In addition, with the development of IT artifacts, there is a potential to instantly communicate relevant information to end-users. Therefore, a suitable ICT-based intervention must be designed to address this research problem.

- From farmers' perspective, there is a need to change the work traditions of how farmers manage crop disorder incidents. The solution's success depends on whether they trust and accept the solution. To better understand how the solution works in farmers' context and how they operate it, the researcher has to communicate with them to get their opinions and feedback to revise the solution concurrently. Furthermore, constant interaction is also required to provide relevant training, technical assistance and troubleshoot if end-users encounter any problems.

In the literature, problems with the above characteristics are known as wicked problems (Ackoff, 2016; Cole, Purao, Rossi, & Sein, 2005). Finding a solution to such problems requires active interactions between researchers and end-users to better understand the problem within its environment. Moreover, a complete checklist of requirements for such issues cannot be derived at one time; rather, it evolves iteratively. Therefore, as concluded in Chapter 2, developing an ICT-based intervention is an appropriate solution to the problem identified in this research. Therefore, the researcher should select the research methodology based on its ability to solve wicked problems, support users' active collaboration, and encourage the development of an ICT-based intervention with an iterative nature.

3.2 Action Design Research

In ICT-based research, the objective is to intervene in a real-world problem through designing an artifact for better outcomes. Research paradigms in ICTs are twofold: action research (AR) and design science research (DSR) (Järvinen, 2007; Lau, 1997). These are widespread and popular research methodologies in the discipline of ICTs (Sein et al., 2011). The AR approach describes a process of investigation and inquiry that occurs as an action is taken to solve a problem (Tripp, 2005). The objective of AR is to introduce a change in the problematic situation while researching the phenomenon of interest. AR is a community-based study and working with the community to find a solution to a problem in context and is used for improving conditions and practices in a range of environments (Baum et al., 2006; Cohen et al., 2017). Generally, AR has widely applied in social sciences related studies, and it is a concurrent process of taking action and doing research, which is linked together by critical reflection (K. Smith, 2010). Notably, the knowledge is created through action and at the point of action-taking.

In contrast, in DSR, researchers attempt to create new and innovative artifacts to extend the boundaries of human and organizational capabilities (A. Hevner & Chatterjee, 2010; Peffers et al., 2007). In DSR, the designer answers questions relevant to the problem by creating innovative artifacts, thereby contributing new knowledge to the body of scientific evidence (A. R. Hevner, 2007; Pries-Heje et al., 2008). Here, the DSR takes the technological view of the IT artifact and pays less attention to its shaping by the organizational context. Moreover, an understanding is gained while building and deploying the artifact (Peffers et al., 2008).

One of the significant problems identified in both AR and DSR is that the artifacts under study are designed and developed in a slightly deviated manner from the organizational environment in which they would be used (Bilandzic & Venable, 2011; Sein et al., 2011). In DSR, all the research activities will be sequentially taken place. As a result, the evaluation activity in an organizational context is separated from the implementation of the artifact (A. Hevner & Chatterjee, 2010; Kuechler & Vaishnavi, 2008). However, on the other hand, the AR stresses that the artifacts must emerge in interaction with organizational elements (concurrent execution). Similarly, in AR, there is no such IT artifact involved; it is a change in work practice/flow, improving strategies, and knowledge of the environments within which the users practice (Haj-Bolouri et al., 2017; Tripp, 2005). However, in DSR, the researchers can come up with new innovative artifacts to address a class of problems. In general, there is a strong interdependence between the design of an artifact and its use in the organizational setting, and this must be captured during the development stage of any artifact (Cole, Purao, Rossi, & Sein, 2005; Livari, 1992).

As a further development, a new methodology called action design research (ADR) was proposed by extending the principles of AR and DSR and by addressing the limitations identified in both methodologies (Orlikowski & Iacono, 2001; Sein et al., 2011). The ADR methodology attempts to solve research problems encountered in a specific organizational setting by intervening, constructing, evaluating and an ICT artifact that addresses a class of problems typified by a situation and the decision for or against another repeated cycle (Haj-Bolouri et al., 2016; Sein et al., 2011). Therefore, in ADR, a strong connection is expected between the research activities and the participation of researchers, practitioners, and end-users for better outcomes (Livari, 1992). This will help the researchers to develop an innovative artifact to address a class of problems while evaluating the artifact in the organizational settings concurrently (Haj-Bolouri et al., 2018). The processes involved in ADR are outlined in Fig. 3.1. The ADR methodology has four stages: problem formulation; building, intervention, and evaluation; reflection and learning; and formalization of learning. The research begins with an investigation and articulation of the problem, followed by iterative design and development of the artifact, and then research reflection (Mullarkey & Hevner, 2019; Sein et al., 2011). Further, ADR methodology lay down seven principles (P1 to P7 in the below description) to guide the researcher through the process. A detailed description of the activities involved in each stage of the ADR process is given below:

Problem Formulation

In general, the ADR process is triggered by a real-world problem. The initial stage involves the preliminary research and investigation of the problem, including narrowing it down to a research opportunity. The problem formulation stage is also based on existing knowledge gained from practitioners, end-users, other researchers, and the relevant literature. Therefore, the higher-level objective is divided into manageable sub-tasks and assigned to a suitable research group. This stage emphasizes the principles of practice-inspired research (P1) and a theory-ingrained artifact (P2). P1 stresses the need for a context for developing an appropriate solution for a real-world problem and validating that solution. P2 indicates the need for an informed mind to develop solutions that incorporate the knowledge from the literature and the researchers' participation.

Building, Intervention, and Evaluation (BIE)

The second stage of ADR focuses on building an effective artifact to intervene in a problem space with the aim to create positive outcomes. Here, researchers collaborate closely with domain experts to design, develop, and refine the artifact. This is achieved via a series of cycles of building, intervention, and evaluation of the artifact. As these cycles progress, the artifact is further enhanced based on the results from previous cycles and will serve as a basis for subsequent cycles. Reciprocal shaping (P3), mutually influential roles (P4), and authentic and concurrent evaluation (P5) are the principles defined in this stage.

P3 emphasizes the dynamic nature of the problem being studied and the importance of the highly collaborative, user-centred nature of BIE cycles to develop an artifact. Moreover, the interactions between researchers and domain experts result in better decisions being made over many iterations. Such interactions also help to incorporate unpredictable elements resulting from the dynamic nature of the problem space into the artifact's development process. P4 highlights the need for mutual understanding between the parties involved in the study and the importance of each individual's contribution. Finally, P5 emphasizes the need for a concurrent evaluation of the artifact and the activities linked to the building and intervention of the artifact.

Reflection and Learning

The reflection and learning stage occurs iteratively and in parallel with the first two stages. In this stage, researchers reflect on the artifact's evaluation to guide the design process, understand how well the research process adheres to ADR's guiding principles, and learn the relevant implications of the study. This stage adheres to one principle, which is that of guided emergence (P6). This encourages researchers to adhere to P2–P5 throughout the design process of the artifact and reflect critically on the effect of these principles on the artifact design.

Formalization of Learning

The last stage of ADR occurs once the BIE cycles are completed, along with the artifact's reflection and learning. This stage aims to cast the artifact's insights into a more general class of problems. It embraces one principle, which is defined as the generalization of outcomes (P7). This guides researchers to reflect their contributions on a broader level of problems by generalizing the artifact's elements.

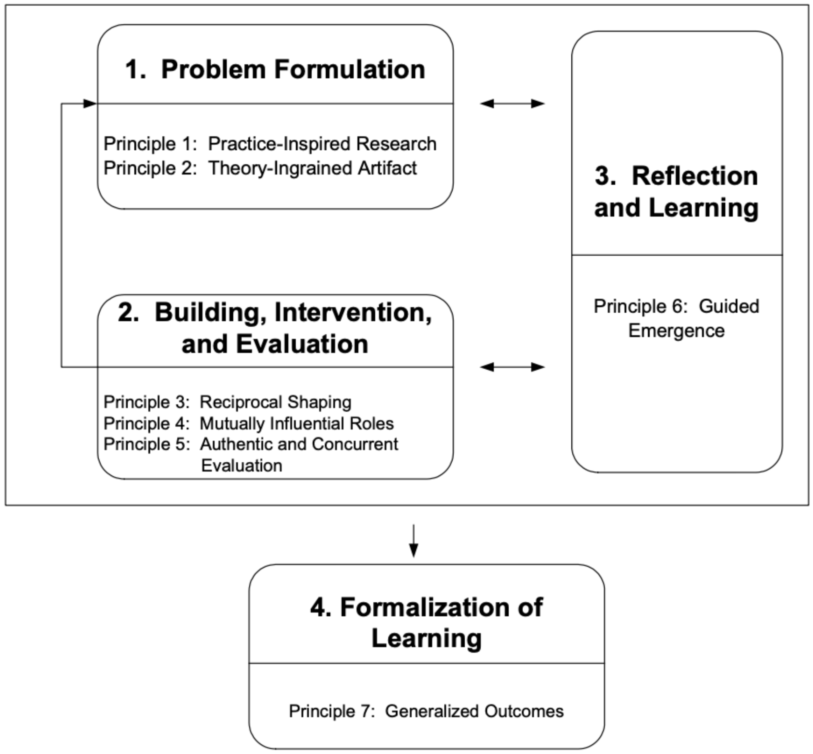


Figure 3.1 ADR stages, Source: (Sein et al., 2011)

3.2.1 Employing Action Design Research

This research employs ADR as the research methodology based on the characteristics of the research problem as identified in section 3.1. To better understand the steps to undertake, the researcher structured the overall research study process into separate stages and assigned relevant activities to each stage as illustrated in Fig. 3.2. These stages are identified as problem identification, conception phase, research and development, and dissemination. Initially, a higher-level research aim was formed in the problem identification stage concerning farmers' needs with respect to crop disorder management. This was discussed in Chapter 1. Similarly, a thorough literature study was also conducted in the problem identification phase to discover more about the problem domain, gaps in the literature, and different solutions proposed to address the identified problem as presented in Chapter 2.

Thus, the main research question of this thesis was formulated as *How to effectively identify crop disorder incidents present based on field observations?* To investigate the main research question, the following set of sub-research questions were defined:

- *RQ1: How can the field-level observations relevant to crop disorders be effectively captured in practice?*
- *RQ2: How can the crop disorder incidents be identified based on the field-level observations being captured?*

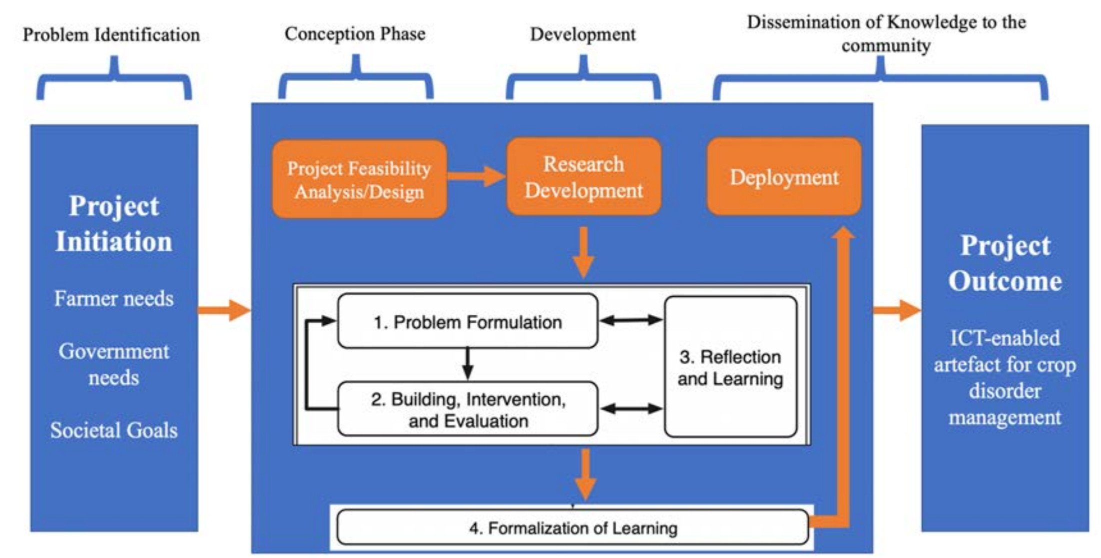


Figure 3.2 Research plan

In the conception phase, a study was carried out to determine the feasibility of forming a research team consisting of different subject experts such as entomologists, pathologists, socio-economists, and agriculture instructors to collaborate and explore a possible solution to the problem being investigated. Accordingly, a multi-disciplinary research team (ADR team) was formed that consisted of the principal researcher from Western Sydney University (WSU), Australia, a supervisory panel from WSU and University of Colombo (UOC), Sri Lanka, socio-economists from Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI), Sri Lanka, and agricultural instructors, agriculture entomologists and pathologists from the Department of Agriculture (DOA), Sri Lanka which together strengthened the collaborative effort.

The expertise service provided by different subject experts in the ADR team is outlined below. The researcher modelled and developed the technology platform with the help of a supervisory panel and a technology development team to better manage crop disorder incidents, capture necessary agri-knowledge from subject experts, and convert it into a decision-support knowledge base. In addition, the researcher provided relevant ICT-related training to the other team members and conducted response evaluations as well. The DOA compiled the collection of published agri-knowledge and made that available to the researcher to develop the intervention. This included the information related to crop and varieties, crop disorders, and associated symptoms and control measures. In addition, the DOA also participated in the deployment and monitoring activities of the solution among farmers and responded to farmer queries in a timely manner. HARTI coordinated with the collaborative institutes, relevant officials, and farmers and acted as a project management team to drive the project, including organizing focus group discussions among the ADR team members. In addition, HARTI also conducted a baseline study among selected farmers, provided training to farmers, deployed the intervention, and conducted weekly monitoring of the artifact usage by farmers, periodic site visits and post-evaluations.

In the development phase, the research was structured using ADR methodology, and the ADR consists of different stages as identified in section . As illustrated in Fig. 3.2, in this phase, the artifact evolved through a series of iterative cycles to address the shortcomings of the previous cycle, followed by evaluations. Accordingly, the researcher chose to carry out several intermediate steps to develop an artifact to solve the identified problem. Overall, two research iterations were conducted as part of the research journey. The activities that take place in iteration one is presented in Fig. 3.3. During iteration one, the researcher attempted to refine the problem and challenges being identified in the crop disorder management process with the assistance provided by the subject experts of the ADR team. Accordingly, a conceptual solution and a set of design requirements were derived as an outcome from the above interaction. Further, to make the design requirements suit the context of farmers, a baseline study was also conducted in iteration one to understand the information needs of farmers, socioeconomic status, access to ICT-based tools, and experience in using ICT-based tools in farming. The analysis of the results collected from the baseline study is discussed in Chapter 4. This step established the researcher to understand the background of the participants that led to derive robust design requirements of the artifact that works well in their context.

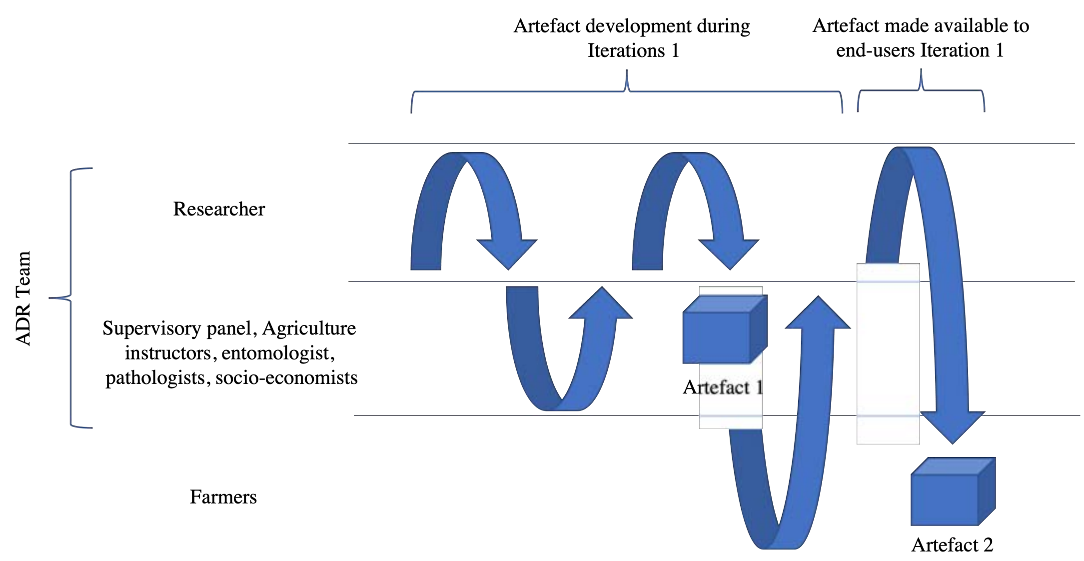


Figure 3.3 Research iteration one

Operationalizing the above findings allowed the researcher to move ahead to implement a suitable solution. Based on the evidence collected from the baseline study, a mobile artifact was considered as a potential tool to communicate the relevant information to farmers. After the implementation stage, the artifact was made available to the farmers through comprehensive deployment, and the farmers trialled the artifact for one cultivation season. During this period, the participants have used the artifact to report field observations, and in turn, the system attempted to identify the crop disorder incidents based on the provided information in an automated manner. At the end of the cultivation season, a number of experiments were conducted among the participants to assess the effectiveness and usability aspects of the artifact. A detailed discussion on the development of the artifact and the results of the experiments is presented in Chapter 5. Furthermore, as part of the experiments, a post-evaluation study was also conducted among the participants after the trial period. With the travel restriction imposed by the Sri Lankan government due to the spread of the COVID-19 pandemic, a post-evaluation study had to be conducted remotely.

In the reflection and learning stage, the researcher found that the results of the experiments revealed both positive and negative aspects of the artifact. Farmers providing incorrect information with respect to the field observation was one of the notable drawbacks found from the outcome of iteration one. In iteration two of the research, the researcher and the other ADR team members attempted to understand the likely areas where further improvements could be made to the artifact deployed in iteration one. Afterwards, the identified refinements were taken into consideration, and a modified version of the artifact was developed and deployed among a different group of participants. The reason for targeting a different group of participants was again due to the travel restriction that was in place; however, by the time, the researchers were able to travel up to a certain distance. Thus, the researcher had to develop a plan to experiment with the refined artifact with a new group of farmers within the allowed distance. A detailed explanation of the above activities is presented in Chapter 6. Further, in summary, the activities that take place in iteration two of the research is presented in Fig. 3.4. Finally, the research outcome was generalized to address a class of problems as presented in Chapter 7, and the overall reflection process directly satisfies the principle of generalization of results (P7).

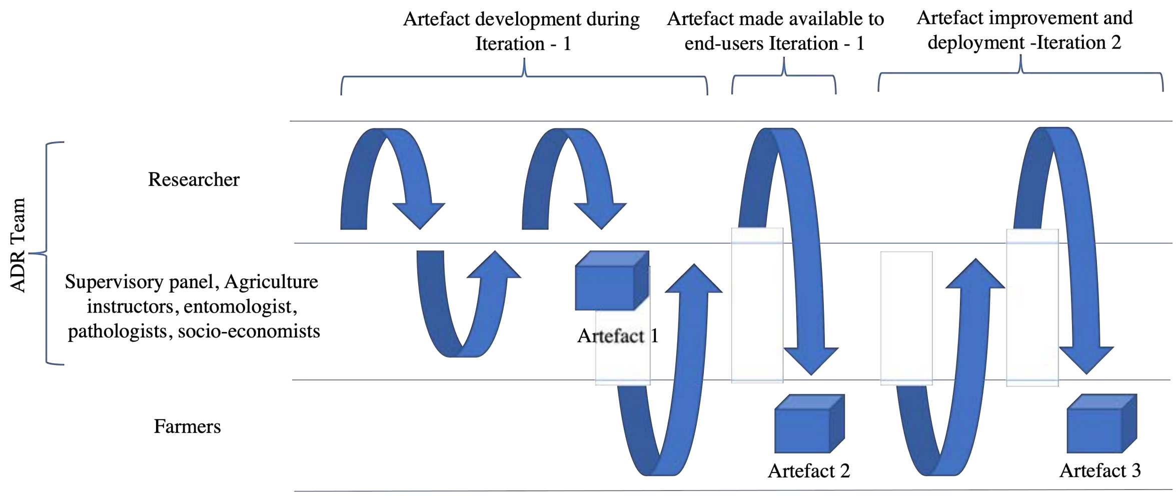


Figure 3.4 Overall Research iterations

3.3 Research Design

3.3.1 Crop Selection

Crops were decided to be chosen mainly based on subject experts' opinions, focusing on those with the extensive application of agrochemicals. Even though high agrochemical usage can be seen in many food crops, specific factors such as the deployment convenience of the proposed intervention and closer distribution of farms in the identified study locations were considered to decide on suitable crops. Accordingly, this research was focused on the paddy crop. Paddy production is the main cultivation in Sri Lanka, and farmers face crop losses at various stages of paddy cultivation (Dhanapala, 2007; Nugaliyadde et al., 1997). Moreover, paddy is cultivated by the highest percentage of the farmers in Sri Lanka (Esham & Garforth, 2013). This will pave the way to easily find participants for this research for a good evaluation of the proposed intervention.

3.3.2 Study location

As mentioned in Chapter 1, Sri Lanka has three types of climatic zones, namely, wet, dry and intermediate zones. In addition, the types of crop disorders that affect paddy cultivation differ with the climatic zones as the spread of crop disorders are influenced by climatic parameters (Sathischandra et al., 2014). Moreover, paddy is cultivated in many districts of Sri Lanka henceforth; the extent of paddy cultivation, extensive usage of agrochemicals, the deployment and travel convenience of the researchers must also be considered as additional factors to decide on the study locations (Esham & Garforth, 2013). Henceforth, three Sri Lankan districts, namely Matara, Polonnaruwa, and Kurunegala, were selected to represent wet, dry, and intermediate zones while satisfying the rest of the selection requirements. Furthermore, each district consists of multiple agrarian service centres (ASCs) that provide extension services to farmers through agricultural instructors. Farmers were attached to each ASC depending on the location of their farm fields. Thus, two ASCs from each selected district were chosen in consultation with subject experts and agricultural instructors. The chosen study locations for the deployment of the artifact are illustrated in Fig. 3.5.

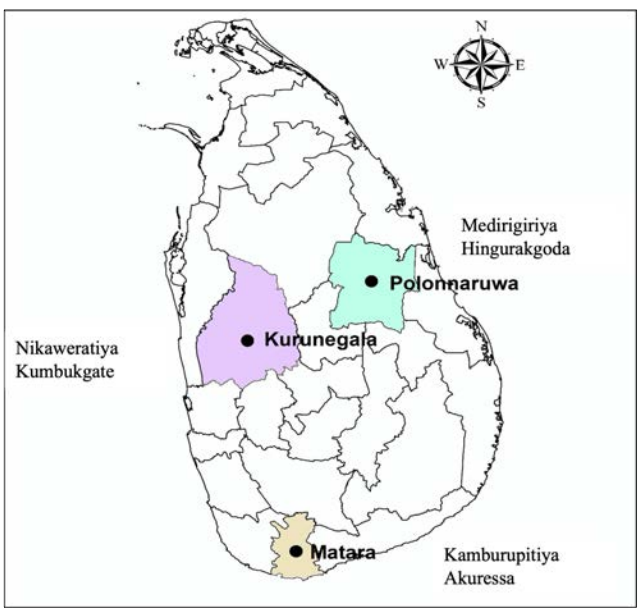


Figure 3.5 Study locations

3.3.3 Sampling approach and participants

For the participants, it was important to select farmers involved in paddy cultivation who have direct experience with, or immediate access to, various ICT-based tools and who are willing to support this exercise. Although a list of farmers can be obtained from relevant ASCs, the information about the farmers who use or are exposed to ICT-based tools was not available; thus, the non-probability sampling method was chosen as a sampling method. Further, probability sampling could not be applied because it was difficult for the research team to give farmers an equal chance of being selected within the total population. From a theoretical perspective, all farmers were potential respondents; however, it was difficult to identify the appropriate participants. Therefore, the snowball sampling technique was used to determine the number of required participants. In this technique, the study begins with only a few farmers who then ask other farmers to join the sample group.

In general, a large sample size ensures higher accuracy of results and a better balance between the proportion in the sample and the population (Denscombe, 2007). However, some crucial factors can restrict the findings as a result of the sample size, such as time and resource constraints (Blaikie, 2000). For these reasons, researchers may research on a small scale that consists of a sample size of 30–250 participants (Denscombe, 2007). Accordingly, the researcher selected 60 paddy farmers from each district (a farmer may belong to any of the district's ASCs); thus, the entire sample consisted of 180 paddy farmers. In Sri Lanka, farmers cultivate paddy during two monsoon seasons, called Maha (September to March) and Yala (May to August) (Suppiah, 1985). Therefore, for this research study, the Maha season of 2019/2020 was when the solution was deployed among the farmers for practical use.

3.4 Data Collection Methods

3.4.1 Key Informant Interviews

Key informant interviews involve interviewing people who have domain knowledge on the aspects of the problem being investigated. This research's key informants were the agricultural instructors, agriculture scientists, subject matter specialists such as entomologists and pathologists, and farmer leaders in the identified study locations. Moreover, in this research, knowledge was gathered concerning three essential aspects: (a) understanding of crop disorder identification in paddy and appropriate control methods, (b) potential for the development of an ICT-based solution, and (c) responses from the participants in terms of effectiveness and usability of the solution. This information is crucial for the robust development of the solution and its deployment within the farming community.

3.4.2 Focus Group Discussions

Focus group discussions (FGDs) were initially carried out with the farmers to disseminate information about the artifact and obtain their initial response. The discussions helped in many ways to develop the artifact in a manner that is better suited for farmers' requirements. Another set of FGDs was conducted to provide farmers with training on how to use the proposed intervention. The farmer or any other representative of the farmer who could use the artifact underwent the training program. Moreover, the respective agricultural instructors were also participated in the FGDs to understand the workflow and the artifact's operations.

3.4.3 Questionnaire Survey

Initially, establishing the baseline study among the selected participants was required to understand the ground situation. Therefore, the research team developed a pre-tested structured questionnaire and distributed it among the farmers (see Table B.10). Similarly, a post-evaluation survey was also developed to understand the behavioural responses from the farming community after using the proposed intervention and distributed among the farmers at the end of the study period (see Table B.12). The results were collected before and after the cultivation, period to evaluate the success of the intervention. The team considered the following factors during the design of the questionnaires;

- Socioeconomic background of the farmer group, including age, education, income, access to land, network connectivity, experience with ICT-based tools, and their usage in agricultural activities, including crop disorder management.
- Known practices employed by the farmers, especially with crop disorder management in paddy cultivation.
- Farmers' attitudes at the inception of the project in terms of usefulness, the credibility of information, user-friendliness, and change readiness.
- Expected behavioural changes from farmers due to quick response rate from agricultural instructors for farmer queries, adoption of control methods suggested through the artifact, reduced dependency on unreliable sources to seek advice, changes in agrochemical use, and following recommended control methods and best cultural practices.
- Farmers' rating of the novel approach toward providing timely information that is actionable against the conventional extension approaches they had been exposed to.
- Empowerment aspects such as how farmers are satisfied with the intervention, trust toward such intervention, and willingness to share with others.
- Changes in the application of agrochemicals, adaptation of best practices for the prevention and control of crop disorders, and changes in farm outputs in terms of quality, yield, price, and thereby net income.

3.5 Assumptions and Constraints

- The research was carried out in three geographical locations of Sri Lanka, and variations can occur in different areas. Therefore, the external validity of this research remains naturally limited.

- This research employed a snowball sampling approach to identify the participants. This approach is considered an effective sampling strategy from the perspective of the research design and the choice of research methods because it highlights the characteristics and behaviours of the participants involved in the research, which was hidden knowledge. The main drawback of the snowball sampling approach is the difficulty in generalizing the results to a larger population due to the sampling bias. However, at this stage, obtaining an in-depth understanding of how the proposed solution will work was considered an essential determinant of this research.

- The use of ICT-based agricultural information services is a comparatively new concept in some rural areas of Sri Lanka. Therefore, the lack of digital experience of end-users may influence the subjects of investigation. Initially, the artifact was pre-tested and examined by the agri-related subject experts within the ADR team to improve the clarity of the provided information. Due to a lack of digital experience, some farmers struggled to articulate their concerns and feedback after the artifact was deployed among farmers. This made it challenging to draw any conclusions regarding improving the user experience.

- During the later part of this research, the ADR team faced difficulties in visiting the farmers to collect post-evaluation data due to the COVID-19 travel restrictions. Thus, the researcher had to accommodate certain changes to the experiment design. As a result, the post-evaluation survey used in the research could not capture the changes in quantitative information with respect to agricultural production, agrochemical usage, the inputs used, yield produced, and production cost and profit as use of the proposed solution; instead, the relevant qualitative information was collected from farmers by contacting them via the telephone.

Chapter Four

Problem Formulation

4.1 Analysis of baseline situation

Designing a solution to address the challenges identified in the crop disorder management process as explained in Chapter 1 and, at the same time, meet the exact requirements of farmers is a complicated task. However, putting the expectations of farmers first will assure that these needs are fulfilled. A good design needs a thorough understanding of users' behaviour and the technology behind the solution (Thimbleby, 2008). Hence, the objective of the proposed solution is to create a satisfying experience for farmers and make the solution usable for their needs.

Accordingly, a baseline study was conducted among the selected paddy farmers. In addition, the baseline study was designed to assess the participants' socio-economic situation, current farming practices in paddy cultivation, awareness of crop disorder management practices, challenges associated with crop disorder management, exposure to ICT-based tools in farming, and readiness to adopt a technology-based solution. The results collected during the baseline study also helped the researcher develop the actual scenarios involved in the crop disorder management process, visualize the conceptual solution, and understand the design requirements of developing a suitable IT artifact. In addition, the baseline study was designed to collect results from farmers based on their involvement in the 2018/19 Maha and the 2019 Yala cultivation seasons. These cultivation seasons will henceforth be referred to as the Maha and Yala seasons.

4.1.1 Socio-economic profile of participants

Socio-economic characteristics of participants

The sample accommodates that only 5% of paddy farmers belong to less than 30 years old, and farmers aged 30–50 years composed 50% of the sample. Here, among the farmers who aged 30–50, 58% of them were based in the Polonnaruwa district, 52% in the Kurunegala district and 42% in the Matara district. Finally, farmers aged 50 or above-composed 45% of the total sample. Regarding the literacy of the chosen farmers, more than half (52%) had an education level below GCE O/L[1], while 43% had either a GCE O/L or GCE A/L[2] qualification. More importantly, in the selected sample, 5% of the farmers possessed a tertiary education qualification (degree/postgraduate diploma/postgraduate degree). In regard to employment, nearly three-quarters (73%) of the farmers were mainly employed in farming for their livelihood. Despite the higher likelihood of full-time farmers being selected for the sample, a considerable portion of farmers were employed in the government sector, and paddy cultivation was merely for their own consumption to supplement their income. Further, the mean monthly household income of the total sample was Rs. 79,562, which is higher than the mean monthly household incomes for the Polonnaruwa, Kurunegala and Matara districts that were Rs. 64,525, Rs. 59,661 and Rs. 54,019 respectively (Department of Statistics, Sri Lanka, 2016). A relatively higher income would further ensure the affordability of ICT-enabled solutions and their uninterrupted use by them.

[1] The GCE O/L is a qualification in Sri Lanka conducted by the Ministry of Education based on the Cambridge University, UK ordinary level qualification

[2] The GCE A/L is a qualification in Sri Lanka conducted by the Ministry of Education based on the Cambridge University, UK advanced level qualification

Farmers' participation in community-based organizations

There are many community-based organizations (CBOs) at the village level that help to prosper the livelihood of farmers in Sri Lanka. The farmers also participate in various CBOs, including the farmers' organization, welfare society, rural development society, elderly society and youth society. In the sample selected for the study, it is observed that 92% of farmers had membership in at least one CBO. In Sri Lanka, farmers being involved in CBOs help them to maintain a healthy relationship with agricultural instructors, agriculture instructors, government officials, input suppliers and peer farmers, and also to receive assistance in regard to agriculture production and practices, crop disorder management, input purchase, marketing and for many other reasons. Fig. 4.1 illustrates the membership of the sample farmers in the farmers' organization (one of the CBOs) across the selected study locations. Although the majority of farmers in the sample were members of CBOs, a considerable portion of sample farmers in the Polonnaruwa (23%), Kurunegala (20%) and Matara (15%) districts had no membership in any CBOs.

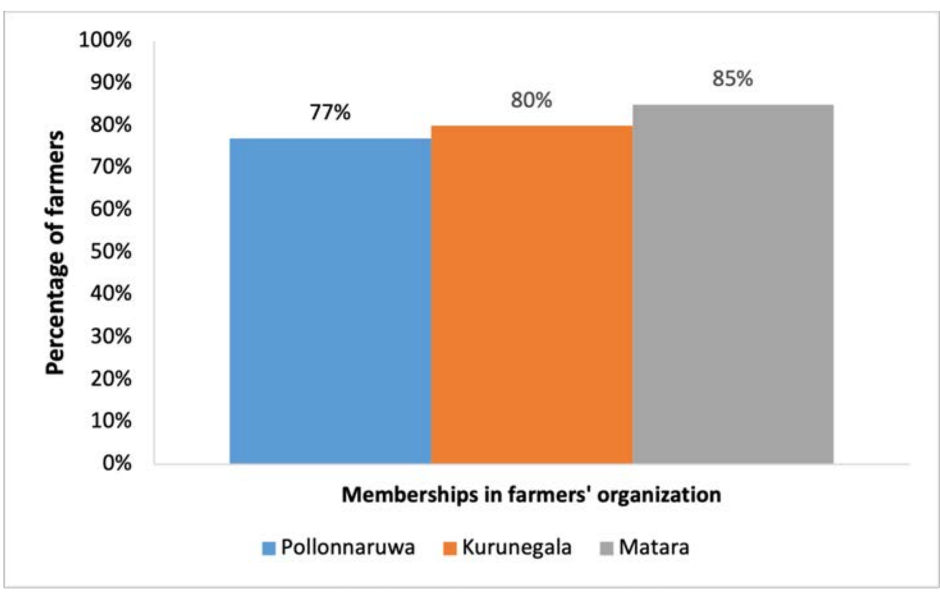


Figure 4.1 Percentage distribution of farmers by membership in the farmers' organization across the districts

Size of land used for the paddy cultivation by the participants

In Sri Lanka, paddy cultivation is conducted in two types of lands; uplands and lowlands, which are categorized based on their elevation from the sea level. Uplands are mainly used to construct houses with home gardens for farmers or any other field crop establishments; however, lowlands are used as large-scale agricultural lands. Most paddy farmers in the Polonnaruwa are large-scale commercial farmers, while in Matara, cultivation is mainly done for self-consumption purposes, and in Kurunegala, production is a mixture of commercial and self-consumption. This is reflected by the larger land plots owned by paddy farmers in the three districts, as shown in Table 4.1. The average size of the lowland plots was 6.33 acres in Polonnaruwa, 4.52 acres in Kurunegala and 3.23 acres in Matara. The total lowland area owned by the sample farmers (Polonnaruwa: 55%; Kurunegala: 33%; Matara: 12%) also highlights the large-scale operation of paddy cultivation in the Polonnaruwa followed by the Kurunegala and Matara. Moreover, of the total 826.08 acres of land possessed by the farmers in the sample, nearly 64% of the total land was upland, and the rest was lowland.

4.1.2 Current status of paddy cultivation

At the time of conducting the baseline study, of the sample, 99% had grown paddy in the Maha season, and 94% had grown paddy in the Yala season. The forthcoming sections describe the various agricultural practices that the selected farmers employed.

Crop establishment methods

In Sri Lanka, farmers use broadcasting and transplanting as the two major crop establishment methods in farming. The sample farmers' preferences regarding crop establishment methods are presented in Table 4.2. Analysis of the data shows that nearly 80% of the farmers used broadcasting and 20% used transplanting as the preferred crop establishment methods in both seasons. Moreover, as noted in Table A.1 of Appendix A, there were simi-

District	Land type	Average size of a land plot (acres)	Total land size (acres)
Polonnaruwa (n=60)	Upland (n=34)	7.01	238.22
	Lowland (n=26)	6.33	164.55
	Total	**6.71**	**402.77**
Kurunegala (n=60)	Upland (n=38)	3.54	134.63
	Lowland (n=22)	4.52	99.5
	Total	**3.9**	**234.12**
Matara (n=60)	Upland (n=49)	3.14	153.71
	Lowland (n=11)	3.23	35.48
	Total	**3.15**	**189.19**
Overall (n=180)	Upland (n=121)	4.35	526.55
	Lowland (n=59)	5.08	299.53
	Total	**4.59**	**826.08**

Table 4.1 Participants' land size by districts and land type

larities and variations in crop establishment methods across the districts. Broadcasting was the prominent crop establishment method employed irrespective of location and season—in particular, 97% of the sample farmers in Polonnaruwa used this method. In contrast, farmers in Matara and Kurunegala demonstrated a moderate tendency for transplanting.

	Crop establishment method	
Season	**Broadcasting**	**Transplanting**
Maha	143 (80%)	36 (20%)
Yala	140 (83%)	29 (17%)

Table 4.2 Crop establishment methods used by the sample farmers

Use of seed paddy varieties

Seed paddy is an essential element in paddy farming. Also, the age groups of seed paddy, seed variety, source of seed paddy and seed rate are important aspects that farmers consider before cultivation. Similarly, varieties can be categorized into different age groups based on crop duration, such as 80–85 days, 3 months, 3.5 months, 4 months, 4.5 months and 5–6 months. Most farmers grow a single variety in a land plot; however, 10% of farmers in the Maha season and 12% of farmers in the Yala season sowed two varieties belonging to different age groups in the same plot. This occurred in Polonnaruwa and Kurunegala, where the plot sizes were relatively larger, and farmers can easily cultivate paddy with different age groups. The paddy varieties sown by the chosen paddy farmers during both seasons are listed in Table A.2 of Appendix A. Some salient features about the use of varieties are:

- The majority (more than 85%) had cultivated short-duration varieties of 3.5 months irrespective of the location and season, and the rest had cultivated varieties of different life spans (i.e. 3 months, 4 months and 4.5 months).
- The most frequently grown varieties in Polonnaruwa and Kurunegala were 3.5 months—that is, Bg 366, Bg 360 (Keeri Samba) and Bg 352.
- Prominently grown varieties in Matara were At 362 and Bg 366 (3.5-month varieties) and Bg 379-2 (4.5-month variety).
- Based on the grain type, paddy varieties can be further classified into Nadu (long grain) and Samba (short grain). The majority of the farmers (nearly 80%) grew Nadu during both seasons.

Yield derived from paddy cultivation

Obtaining a better yield is the ultimate goal of any farmer. However, it depends on a variety of factors, including crop variety, seed quality, crop establishment method and cultural practices followed by the farmers. Similarly, external factors play a crucial role in achieving the potential yield. These include climate variation, crop disorder incidents, wildlife damage and many others. According to the baseline study, the highest average yield of 5,570 kg/ha was registered in Polonnaruwa in the Maha season. The respective figures for Kurunegala and Matara were 4,438 kg/ha and 2,889 kg/ha. In the Yala season, the average yields were 6,365 kg/ha in Polonnaruwa, 4,200 kg/ha in Kurunegala and 2,350 kg/ha in Matara.

Fig. 4.2 illustrates the percentage distribution of the sample farmers according to the average yield obtained during both seasons. It shows that most farmers from Polonnaruwa obtained an average yield of more than 4,942 kg/ha in the Maha (65%) and Yala (82%) seasons. In Kurunegala, nearly 50% of the sample farmers could secure an average yield of more than 4,942 kg/ha during Maha, whereas in Yala, 50% of farmers obtained 2,471 kg/ha to 4,942 kg/ha. The average yield obtained by farmers from Matara was less than that of the other two districts, and it is important to note that 63% of farmers obtained a yield of less than 2,471 kg/ha during Yala.

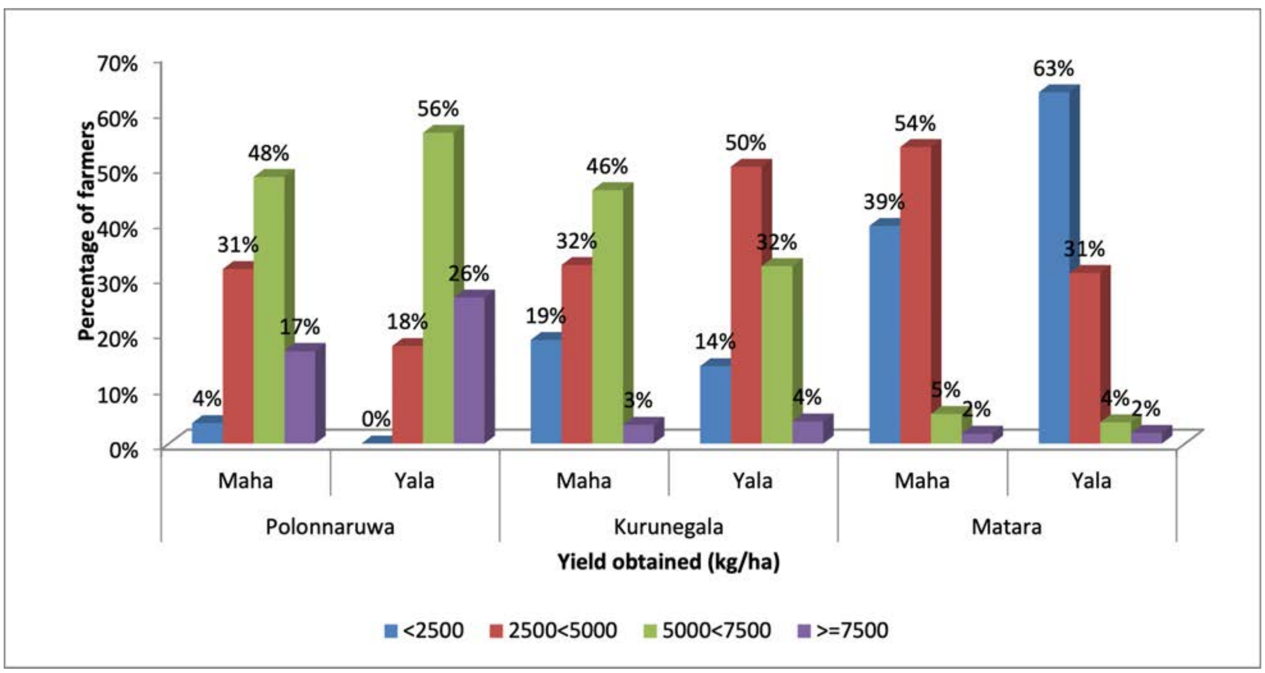


Figure 4.2 Percentage distribution of sample farmers by yield obtained

Yield loss during the paddy cultivation

In many instances, the actual yield obtained by a farmer during a cultivation season may vary from the expected yield. In practice, this is defined as a yield gap, the difference between the expected yield and actual yield obtained per hectare. The yield gap is influenced by many factors and can be either an excess yield (positive) or a yield loss (negative). In order to understand how the actual yield obtained was varied from the expected yield, the baseline study also included the questions about the expected yield, the actual yield obtained, yield losses and the factors contributing to yield loss. Based on the responses collected, the factors that can contribute to the yield loss are presented in Fig. 4.3. Similarly, Table 4.1.2, Table 4.1.2, and Table 4.1.2 list specific observations relevant to yield losses in Polonnaruwa, Kurunegala and Matara in both seasons. Furthermore, the following conclusions were also derived from the responses collected from the participants about the expected yield, yield gap and the factors contributing to yield loss:

- expected yield estimation for Maha in kg/ha: 7,267 in Polonnaruwa, 5,325 in Kurunegala and 3,400 in Matara
- expected yield estimation for Yala in kg/ha: 6,739 in Polonnaruwa, 5,342 in Kurunegala and 3,336 in Matara
- less than 5% achieved an excess yield
- excess yield is a result of fewer climatic variations and therefore a lack of natural disasters, use of good-quality seeds, better cultural practices and minimal crop disorder incidents
- around 31% and 18% of farmers experienced neither an excess nor a loss to their expected yield during Maha and Yala, respectively
- 66% and 77% of farmers experienced a yield loss during Maha and Yala, respectively

- overall, damage caused by crop disorder incidents was the key contributor to yield loss during Maha, accounting for 58% of yield loss
- in Yala, 47% of yield loss was due to climatic changes (drought or heavy rain)
- 5–6% of losses were due to wildlife damage, especially from elephants, peacocks, wild boars and birds
- among the identified factors, minor contributors to crop losses include poor soil condition, low-quality seeds, damage caused by machinery, issues associated with seeding and transplanting, and post-harvest losses.

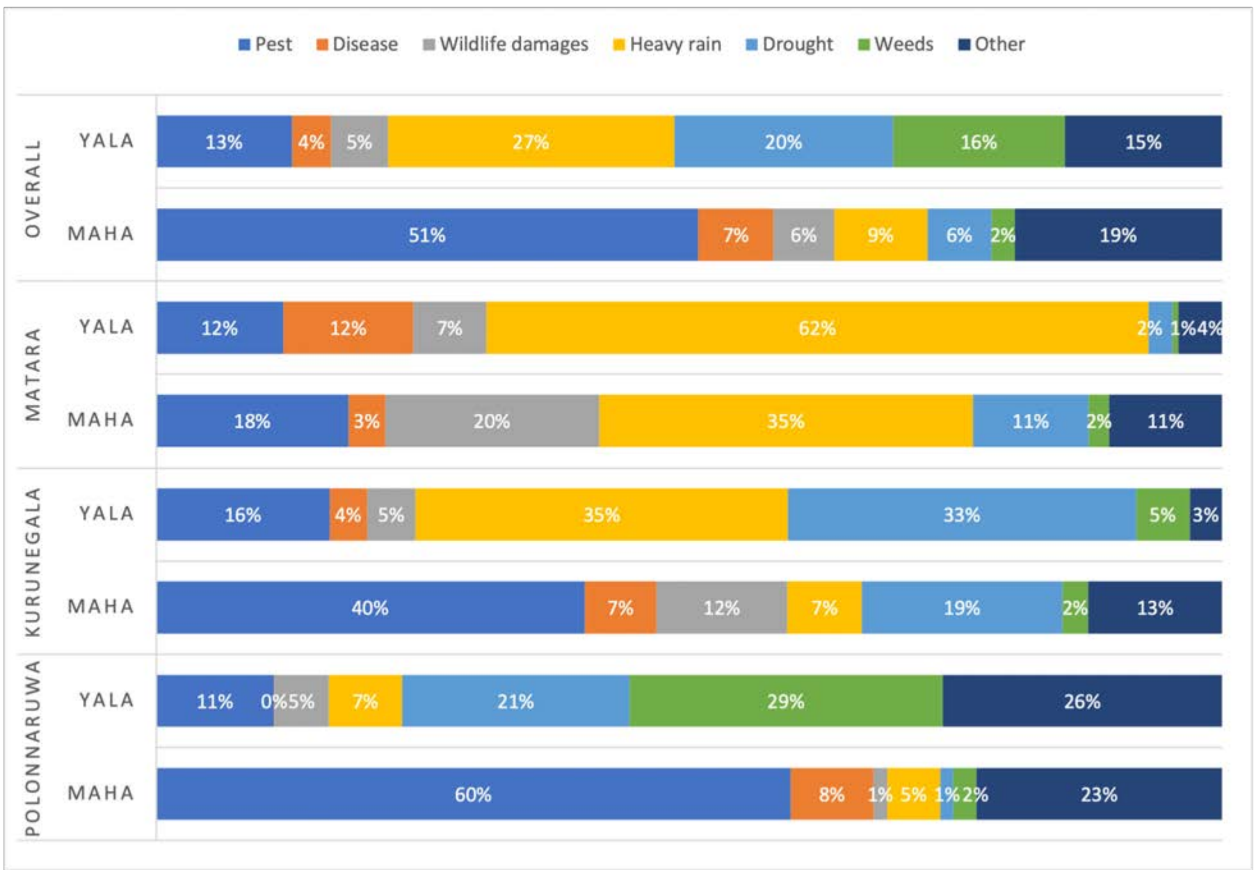


Figure 4.3 Share of yield loss due to various factors

Season	**Causes of yield loss**
2018/19 Maha	• The average yield loss was 1,609 kg/ha. • The main reasons for the yield loss were pest attacks (60%) and diseases (8%). • Rainy weather prevailed, which increased the number of crop disorder incidents. Hence, minimising crop disorder incidents is a prerequisite to attaining higher yields during the Maha season. • Losses due to machinery usage was about 7%.
2019 Yala	• The average yield loss was 1,184 kg/ha. • The yield loss was mainly due to weed growth (29%). • The second most influential factor was the prolonged droughts (21%) that prevailed in the area. Continuous dryness is unfavourable for paddy cultivation; it affects all stages of the crop and ultimately results in poor yields. • Yield loss due to pest attacks in the Yala season was 11%.

Table 4.3 Yield loss in Polonnaruwa

Season	Causes for yield loss
2018/19 Maha	• The average yield loss was 1,268 kg/ha. • Like in Polonnaruwa, the main reason for yield loss was pest attacks (40%). • In addition, prolonged drought conditions and heavy showers together caused 26% of yield losses. • Wildlife damage was a slightly prominent cause of yield loss (12%), followed by disease (7%).
2019 Yala	• The average yield loss was 1,559 kg/ha. • Kurunegala is categorized in the intermediate zone; thus, the prevalence of heavy showers of rain (35%) and prolonged drought conditions (33%) were common reasons for yield losses in Kurunegala. This was well exemplified during the Yala season. • Adverse climatic conditions intensified other factors that caused yield losses, such as pests (16%) and diseases. • The Kurunegala area requires a suitable mechanism to mitigate pest and disease attacks during both seasons.

Table 4.4 Yield loss in Kurunegala

Season	Causes for yield loss
2018/19 Maha	• The average yield loss is 1,026 kg/ha. • Heavy rain was responsible for 35% of yield losses. • Wildlife damage (20%) and pest attacks (18%) significantly contributed to yield losses.
2019 Yala	• The average yield loss was 1,226 kg/ha. • Heavy rain caused severe yield loss (62%). • Pests and diseases equally contributed to yield losses (12% each).

Table 4.5 Yield loss in Matara

Main challenges faced by participants in paddy cultivation

Farmers face many and varied challenges in paddy cultivation in Sri Lanka. As such, during the baseline survey, participants were asked to discuss the challenges they faced during paddy cultivation in the Maha and Yala seasons. The results are presented below and in Fig. 4.4, Fig. 4.5 and Fig. 4.6.

During the 2018/19 Maha season in Polonnaruwa:

- The main challenge was crop disorder incidents (65%), followed by unavailable or expensive machinery (32%), as most farmers were commercial farmers who were willing to mechanize their farming. Other major challenges were water scarcity (18%) as a result of a lack of sufficient water for paddy cultivation when required and a decline in farm gate prices (17%) mainly due to the selling of wet paddy during the peak harvesting period.

- Other challenges included the increased cost of production (13%), weed growth (13%), labour shortage (12%), damage caused by wildlife (8%) and natural disasters (7%).

During the 2019 Yala season in Polonnaruwa:

- The main challenges for the farmers were water scarcity (47%), weed growth (30%), unavailable or expensive machinery (25%) and crop disorder incidents (22%).
- Other challenges include weed growth, water scarcity, pest and disease attacks.

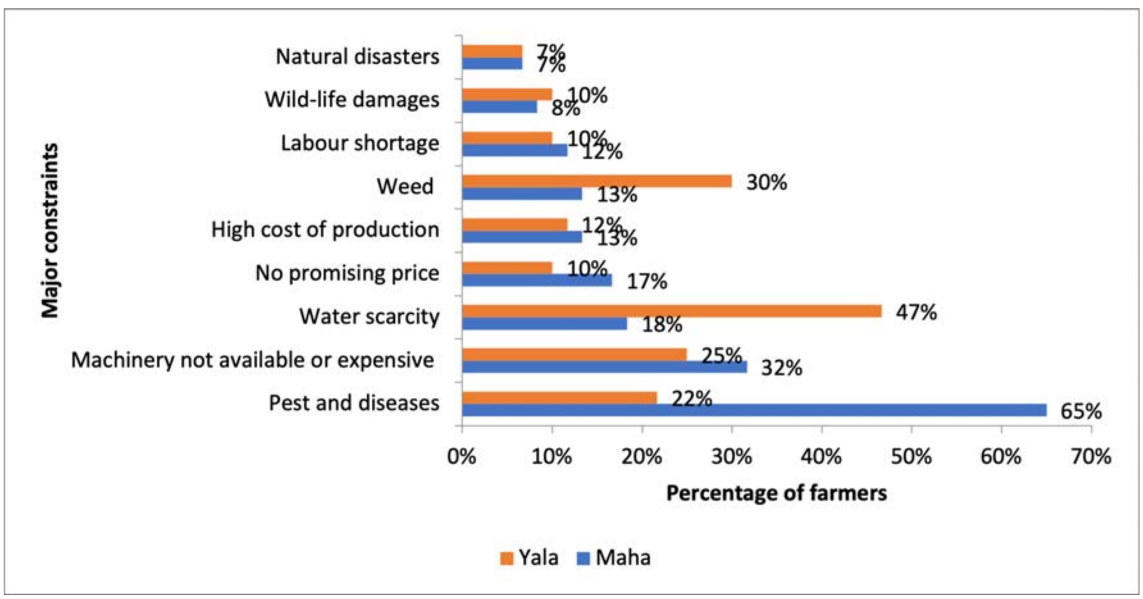


Figure 4.4 Major challenges faced by sample farmers in Polonnaruwa

During 2018/19 Maha season in Kurunegala

- The main challenges were identified as crop disorder incidents (68%), water shortage (28%) and damage caused by wildlife (27%)—particularly by wild boars, elephants and birds.

- Labor shortage (17%) for fieldwork and not receiving a sufficient farm gate price for the paddy (13%) were also identified by many farmers in the area.

During the 2019 Yala season in Kurunegala:

- The main challenges identified by the farmers were inadequate water for cultivation purposes (45%), crop disorder incidents (37%) and damage caused by wildlife (23%).

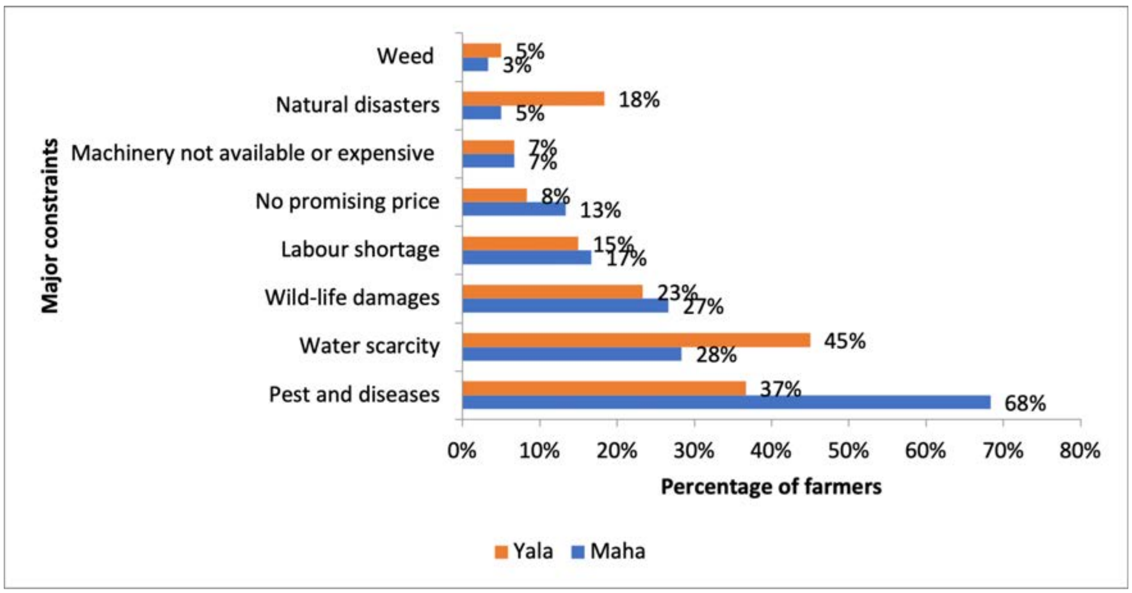


Figure 4.5 Major challenges faced by sample farmers in Kurunegala

During 2018/19 Maha season in Matara

- The main challenge for half of the sample was damage caused by wildlife (52%)—particularly by peacocks and wild boars. Factors such as crop disorder incidents (37%) and natural disasters (30%) such as floods and heavy winds were also identified by a considerable number of farmers.

- Farmers' need for machinery (3%) and low farm gate prices (2%) were identified as the main challenges by a few farmers who were mostly small-scale and self-consumption-oriented farmers.

During the 2019 Yala season in Matara:

- Similar to the Maha season, the main challenge in Yala was also damage caused by wildlife (57%). Crop disorder incidents and natural disasters were identified by 48% of farmers.
- Inadequate water for cultivation (20%) and labour shortage (13%) were also identified by a considerable number of farmers.

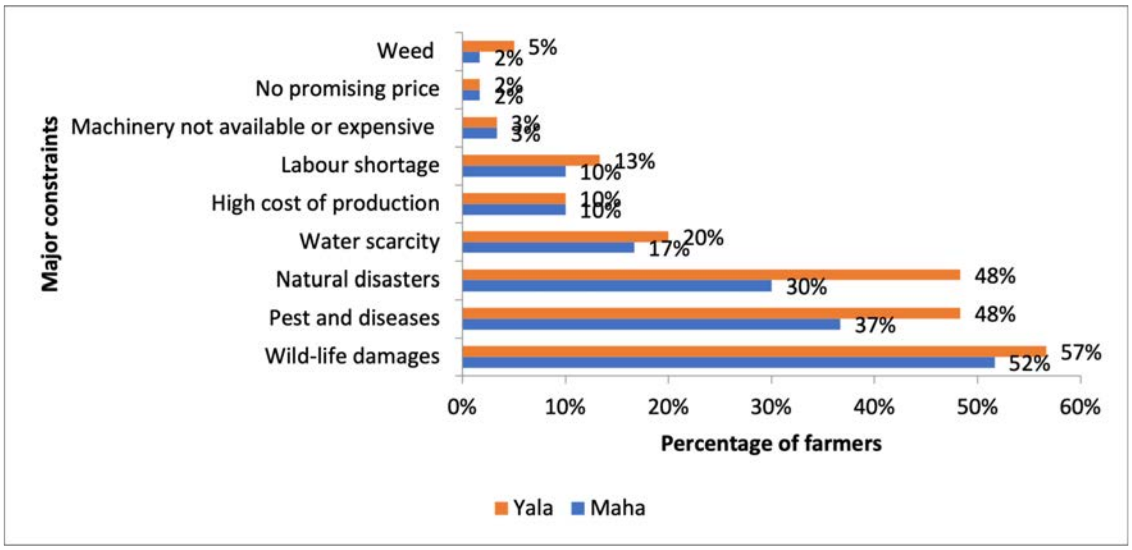


Figure 4.6 Major challenges faced by sample farmers in Matara

4.1.3 Current status of crop disorder management in paddy cultivation

As discussed in previous sections, crop disorder management is a crucial component of paddy cultivation. Further, the management of crop disorder incidents is mainly based on adapting cultural, mechanical, biological and chemical control methods. However, as discussed in Chapter 1, in Sri Lanka, farmers have become extensively dependent on agrochemicals over the years. The legal authority of the regulation of agrochemicals in Sri Lanka is currently with the Registrar of Pesticides (ROP), appointed under the Pesticides Act [3] and the decisions related to agrochemical recommendations are made by the Pesticide Technical Advisory Committee (PeTAC) of the DOA. Thus, the recommendations made available through other sources cannot be considered as trustworthy information. Given this background, this section sheds light on the awareness and adoption of recommended farming practices by the sample farmers to prevent crop disorders in paddy cultivation. This is followed by a discussion of the status of crop disorder management carried out by the sample farmers during the Maha and Yala cultivation seasons.

Awareness of recommended farming practices by farmers

The current status of crop disorder management by the sample farmers was assessed based on their adherence to 12 cultural practices that have been recommended for paddy cultivation by the DOA to prevent crop disorder incidents. These cultural practices, including their short abbreviations, are presented below:

- All farmers in Yaya[4] begin cultivation activities simultaneously—Yaya cultivation.
- Loosening the soil to the specified plough depth of 15–20 cm—Plough depth.
- Adding straw, green leaves and animal manure to the soil and ploughing the land, followed by clearing the bunds before the first land preparation—Organic manure.
- Keeping standing water up to half the level of the bund after land preparation—Standing water.
- Adding partially burnt paddy husk/straw to the field—Paddy husk charcoal.

[3] According to the Pesticides Act No. 33 of 1980, as amended by Act No. 06 of 1994 and Act No. 31 of 2011, the ROP is responsible for regulating pesticides imported to and manufactured in Sri Lanka, assuring their quality and safe use, and assessing and declaring maximum residue limits in agricultural produce (DOA, 2019).

[4] Yaya is defined as the whole paddy land that typically supplies irrigated water in one handover point

- Testing seed germination—Seed germination test.
- Cultivation of resistant varieties—Resistant varieties.
- Complying with recommended seed rates—Seed rate.
- Second ploughing 10–14 days after the first land preparation by ploughing in the opposite direction to the first ploughing—Second ploughing.
- Treating seed paddy with fungicides—Seed treatment.
- Complying with recommended depth and spacing of planting (2–2.5 cm depth and 15x15 cm spacing)—Spacing.
- Complying with recommended rates of urea application—Urea application.

Fig. 4.7 and Fig. 4.8 illustrate the sample farmers' awareness and adoption of the recommended cultural practices to safeguard crops from potential crop disorder incidents. Fig. 4.7 shows farmers' awareness (over 95%) and adoption (over 65%) of the following recommended practices during both seasons: keeping standing water in the field after land preparation, cultivation of the entire Yaya by all farmers simultaneously, loosening the soil to the specified plough depth of 15–20 cm, second ploughing after 10–14 days by ploughing in the opposite direction to the first, undertaking a seed germination test and cultivation of resistant varieties.

However, Fig. 4.8 shows that although more than 80% of farmers were aware of certain recommendations, the rates of adoption were between 45% and 60%. Adding of organic manure—straw, green leaves and animal manure—followed by the clearing of bunds before the first land preparation, complying with recommended rates of seeds and urea application, and undertaking seed treatment are a few of the recommendations that were not adopted by many of the sample farmers. Further, Fig. 4.8 indicates that the application of paddy husks/straw to the paddy field had the lowest rate of adoption, despite awareness of the

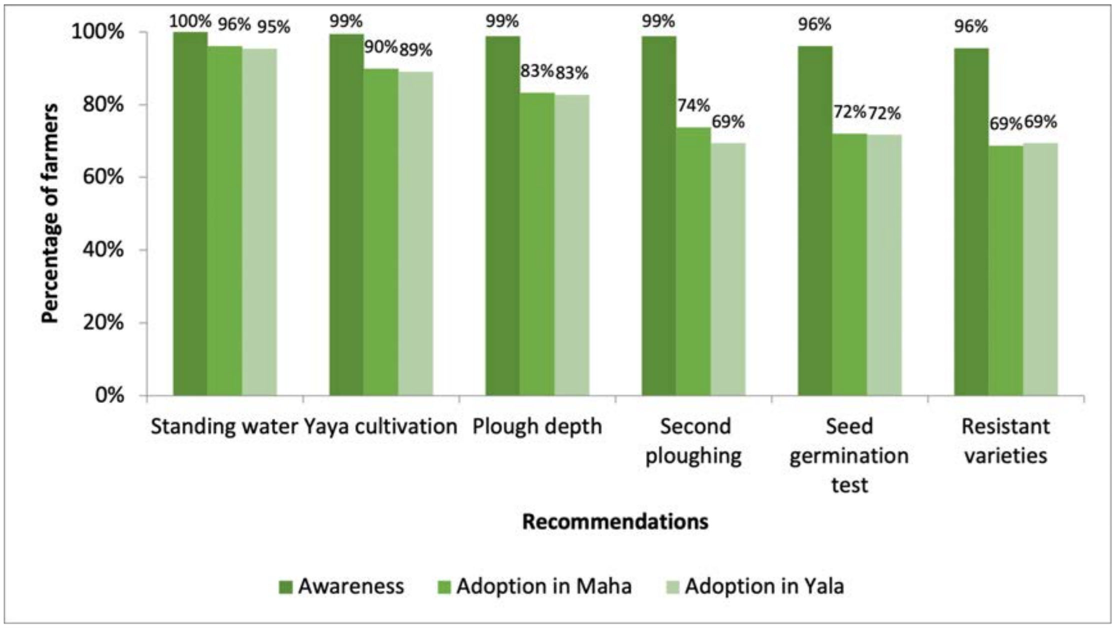


Figure 4.7 Percentage distribution of farmers by awareness and adoption of recommended practices in paddy cultivation-a

practice by more than 80% of the sample farmers. Further, the farmers were also least aware of the spacing and planting depth recommendation in paddy cultivation. The location-specific reasons underpinning in non-adoption of recommended practices in paddy cultivation revealed that the reduced rates of farmers are mainly due to the lack of access to the required information from relevant authorities and sources. Moreover, the lack of attention given by farmers in following recommended practices due to the difficulties in understanding the provided information in practice is also a reason that contributes to the reduced adaptation rates.

Crop disorder management in paddy cultivation

Fungi, bacteria, viruses and pests cause most of the crop disorders in paddy. Of these, most have been recognized by the DOA as crop disorders that cause considerable crop damage at different stages of the crop's lifecycle. According to the DOA, the damage caused by pests and diseases is severe in paddy cultivation. Pests are categorized as major and minor pests

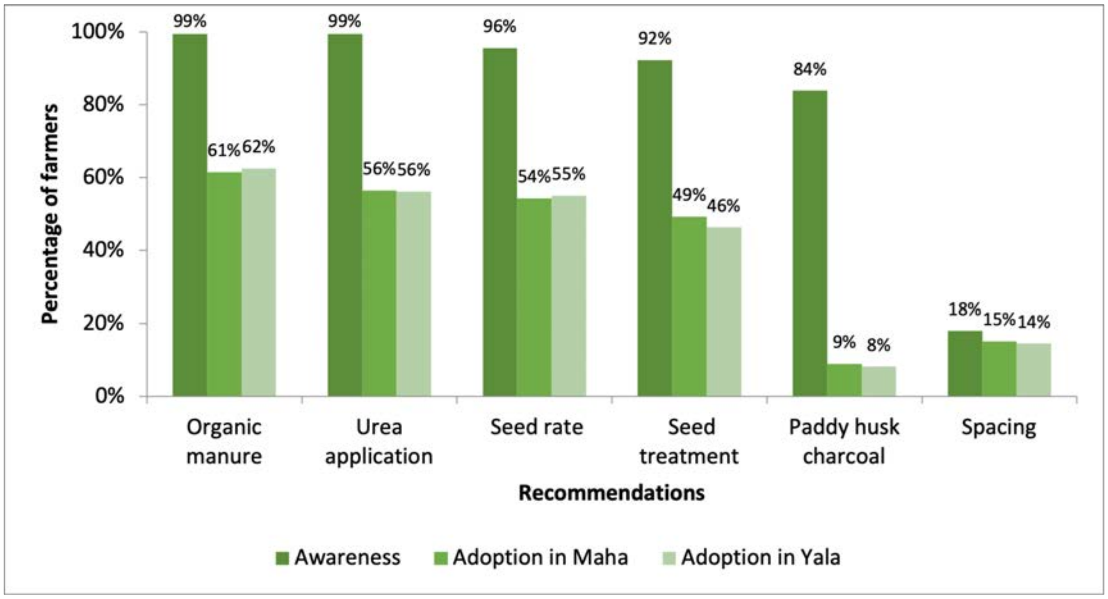


Figure 4.8 Percentage distribution of farmers by awareness and adoption of recommended practices in paddy cultivation-b

based on the extent and severity of the damage. Nematodes and rats are considered major pests, and major insect pests found in paddy cultivation include the brown planthopper, stem borer, gall midge, thrips, leaf folder, rice bug, sheath mite, white-backed planthopper, leaf mite and mole cricket. Common paddy diseases that are found in Sri Lanka include rice blast, sheath blight, bacterial leaf blight, brown spot, foot rot, false smut, narrow brown spot, leaf scales, bacterial leaf streak, grain discolouration and sheath rot.

According to the baseline study conducted in this research, the likelihood of crops not being exposed to a crop disorder attack is rare (6% in Maha and 8% in Yala). Table 4.6 illustrates the occurrence of crop disorder incidents during both seasons across the study locations. Notably, many of the sample farmers stated that they had faced the crop disorder outbreak in their paddy cultivation in both the Maha (48%) and Yala (43%) seasons. Similarly, the sample farmers have also stated that they have experienced repeated crop disorder outbreaks in the Maha season, compared to the Yala season. Thus, the occurrence of three or more crop disorder outbreaks in a single season was relatively low.

Number of crop disorder incidents	Polonnaruwa		Kurunegala		Matara		Overall	
	Count	%	Count	%	Count	%	Count	%
2018/19 Maha	(n=60)		(n=60)		(n=59)		(n=179)	
None	4	7%	2	1%	5	8%	11	6%
One	27	45%	30	50%	29	50%	86	48%
Two	23	38%	22	37%	20	34%	65	36%
Three or more	6	10%	6	10%	5	8%	17	10%
2019 Yala	(n=59)		(n=52)		(n=58)		(n=169)	
None	5	8%	3	6%	5	9%	13	8%
One	27	46%	20	38%	26	45%	73	43%
Two	24	41%	25	48%	20	34%	69	41%
Three or more	3	5%	4	8%	7	12%	14	8%

Table 4.6 Percentage distribution of number of crop disorder incidents in paddy across districts by seasons

Sources of information on crop disorder management

The sources used by farmers to assist their decision-making process can be grouped into reliable and unreliable sources. Although the DOA fulfils the extension needs of farming communities, farmers generally relied on unreliable sources to satisfy their information needs, especially in relation to managing crop disorder incidents. Table 4.7 shows the extent to which the farmers depended on reliable and unreliable sources as their preferred choice for information needs related to crop disorder management. Among the reliable sources, agricultural instructors predominated over other sources such as agriculture research production assistants, research officers and field officers. Conversely, pesticide dealers, input suppliers, peer farmers, and farmers' past experience were considered unreliable sources of information. As shown in the table, 60% of the sample farmers had obtained information from reliable sources, and the remaining 40% relied on unreliable sources. As discussed in

Chapter 2, the limitation of unreliable sources is that the information received from each individual is subjective and may lead to bias, resulting in farmers making incorrect decisions and not following recommended farming practices.

Sources	**Polonnaruwa**	**Kurunegala**	**Matara**	**Overall**
Reliable sources				
Agriculture instructors	32	37	21	90
Agriculture research and production assistants	0	5	13	19
Agriculture research officers	2	1	5	8
Field officers of private companies	0	2	1	3
Total	**34 (57%)**	**45 (75%)**	**40 (67%)**	**120 (60%)**
Unreliable sources				
Pesticide stores or Input suppliers	13	11	12	36
Own knowledge	9	2	6	17
Fellow farmers	4	2	2	8
Total	**26 (43%)**	**15 (25%)**	**20 (33%)**	**60 (40%)**

Table 4.7 Percentage distribution of information sources used by farmers across districts

Application of various control methods for managing crop disorders

The analysis of the various crop disorder management techniques employed by the sample farmers is presented in Fig. 4.9. Among these, chemical control methods were used by the majority of farmers, and cultural or biological methods were also used in the Polonnaruwa (23%) and Matara (4%) districts. Further, farmers from Kurunegala depended entirely on chemical methods, while more than 75% of the farmers employed chemical control methods in the other districts. None of the farmers employed mechanical control methods, mainly because of the additional expenses of purchasing machinery and traps. Importantly, the cultural and biological control methods employed by the rest of the farmers emphasize their willingness to use chemical-free methods to manage crop disorder incidents.

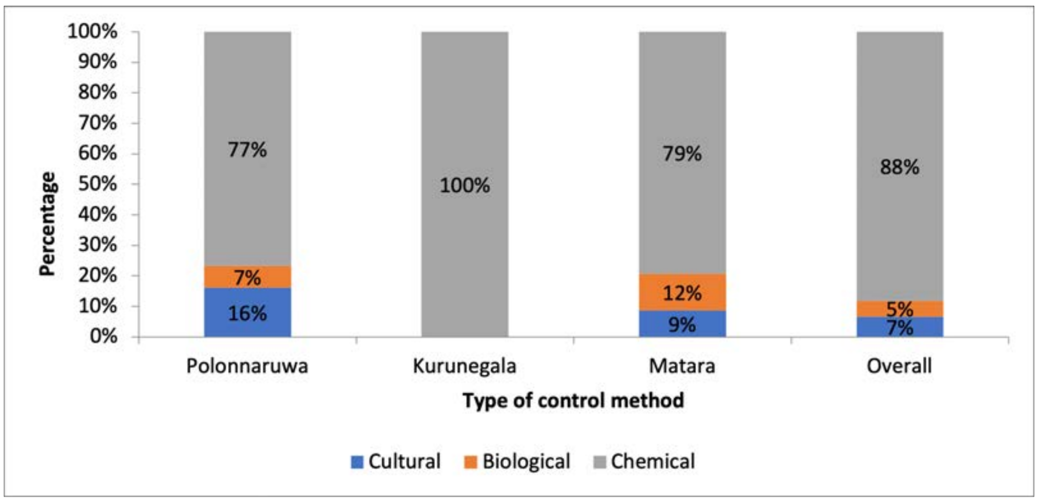


Figure 4.9 Percentage distribution of control methods employed by farmers across districts

Furthermore, farmers' lack of awareness of agrochemical usage was also a common weakness observed across all study locations. For example, farmers used Tebuconazole 250g/l EW (Folicur and Lankem) to control rice blast, bacterial leaf blight, sheath blight and brown spot, but it is particularly recommended for rice blast. Similarly, Hexaconazole 50g/l EC (Eraser) was being used for rice blast, bacterial leaf blight, sheath blight and false smut, but it is recommended only to control sheath blight. Among all of the agrochemical applications used to manage crop disorder incidents, only 5% of the sample farmers adhered to the recommendations. These findings suggest the indiscriminate use of agrochemicals by the sample farmers. The analysis further revealed that irrespective of the study location, the majority of farmers

(68%) tended to apply agrochemicals at the first appearance of symptoms when no serious damage had been done to the crop. Another 29% of the farmers used agrochemicals when they understood that there was potential for the crop disorder to spread, and 2% of the sample farmers applied agrochemicals even before seeing any symptoms.

4.1.4 Participants' access to and use of ICT–based tools

As discussed in Chapter 2, recent advancements in ICTs, especially mobile-based technologies, have significantly improved the flow of relevant information within the agriculture sector, resulting in many positive outcomes. However, before any intervention being implemented, it is important to have a thorough understanding of the participants' knowledge and access to mobile technology. Accordingly, the information related to farmers' access to mobile phones, use of mobile phones, use of farming-related innovative technologies, emphasis on mobile applications, and challenges they faced while using those technologies were collected during the baseline study.

Exposure to mobile technology by sample farmers

The farmers used different types of telephones at the household level—mainly classified as fixed access telephones and cellular mobile phones. There are two types of fixed access telephones (wired and wireless) and two types of cellular mobile phones (feature phones and smartphones). The baseline survey revealed that only a small number of the participants owned a fixed access telephone, whereas the majority used cellular mobile phones. Table 4.8 shows that the number of smartphones used by the sample farmers, which was higher than the number of feature phones, regardless of location. Further, the descriptive responses suggested that the low use of fixed access telephones was mainly because farmers could not carry them when they were outside. The summarized results are presented in Table 4.8 whereby either the farmer or a household member used any kind of telephone.

Types of telephones	Polonnaruwa	Kurunegala	Matara
Fixed access telephones			
Wire-line phones	5 (out of 60)	5 (out of 60)	8 (out of 60)
Wireless phones	12 (out of 60)	12 (out of 60)	10 (out of 60)
Cellular mobile phones			
Smartphones	60 (out of 60)	60 (out of 60)	60 (out of 60)
Feature phones	15 (out of 60)	20 (out of 60)	14 (out of 60)

Table 4.8 Types of telephones used by the individuals in the sample households

The farmers' exposure to mobile phones was determined by how long they had been familiar with mobile technology. Fig. 4.10 presents the results of the analysis of the sample farmers' exposure to mobile phone usage. As shown, 97% of the farmers had been familiar with mobile technology for a varying number of years. More importantly, 82% of the farmers had more than ten years of exposure, which suggests they had abundant experience with mobile technology. Only 3% of the sample identified as farmers aged over 50 years old had no mobile exposure.

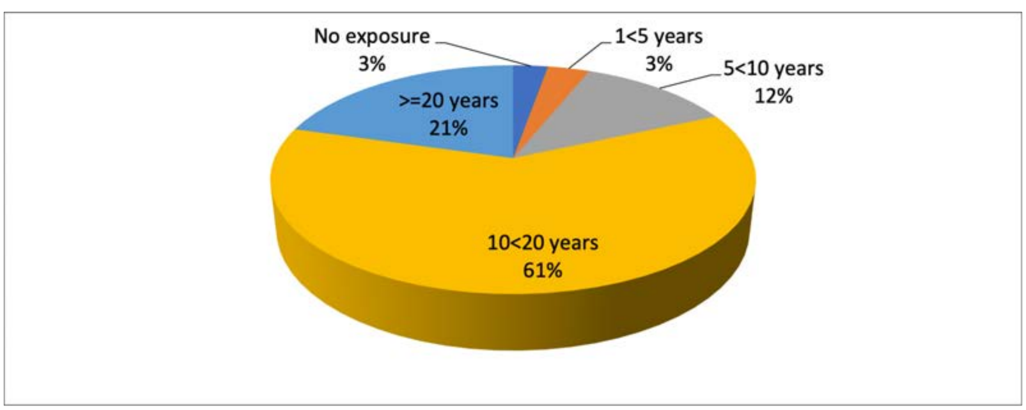


Figure 4.10 Percentage distribution of farmers by years of exposure to mobile phones

Further analysis on the type of mobile phone users revealed that the farmers could be grouped into two, namely, direct and indirect users, based on their mobile phone usage. Farmers who used their own mobile phones were considered direct users, whereas those who depended on other household members were considered indirect users. As shown in Fig. 4.11, Polonnaruwa had the highest percentage of direct users (83%). Fig. 4.12 presents the analysis of the results regarding the reason for using a mobile phone. As shown, the majority of the sample farmers used mobile phones for conversation purposes (incoming/outgoing calls).

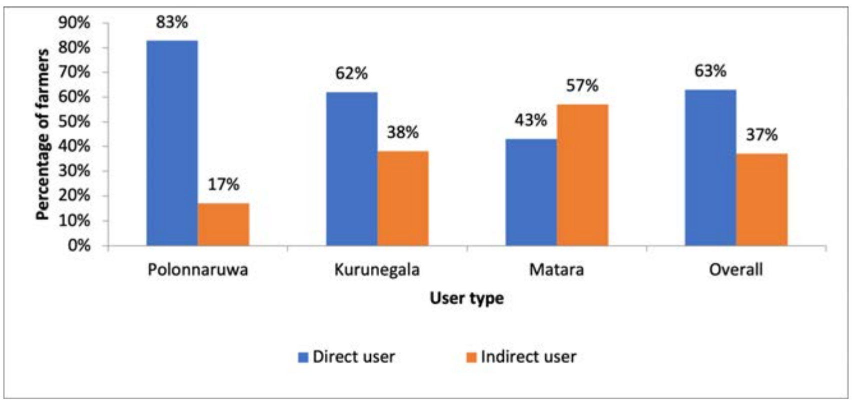


Figure 4.11 Percentage distribution of farmers by user type across districts

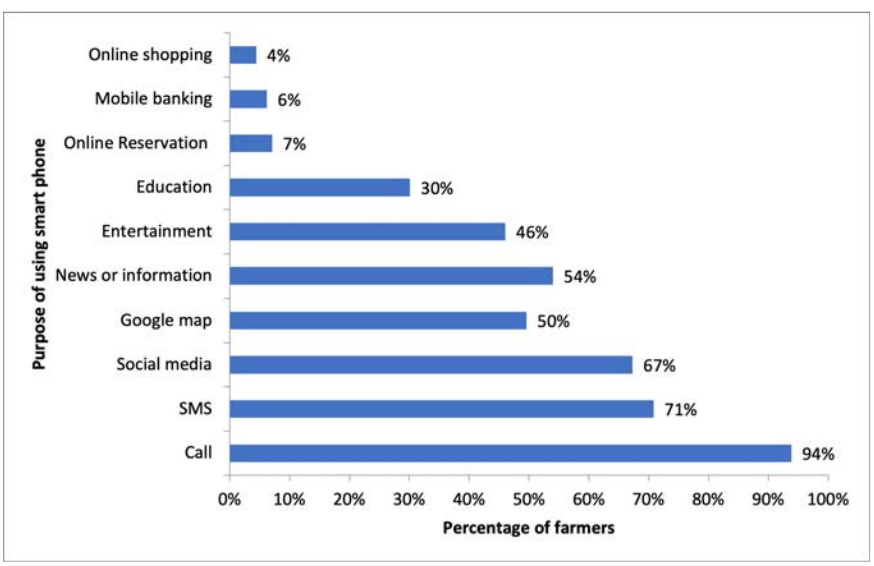


Figure 4.12 Various reasons for using smartphone by sample farmers

In addition, SMS, news services, Google Maps and social media platforms such as Facebook, YouTube and WhatsApp were popular among more than 50% of the farmers in the sample. Farmers also sometimes used their mobile phones as entertainment and education tools. The least used mobile services by the sample farmers were mobile banking, online shopping and online reservations, including hotel and travel bookings. Proper internet access is essential to access all of these services; hence, during the baseline study, the farmers were asked about their situation in regard to internet access and frequency of internet use. The results are presented in Fig. 4.13. Remarkably, 96% of the farmers from Polonnaruwa used the internet; however, a considerable number of farmers in the other two districts had no access to the internet (19% in Kurunegala and 31% in Matara). In addition, a case study of a farmer in the Kurunegala district given below was also obtained to reflect his opinions of mobile phone usage in day-to-day activities. Interestingly, this case study highlights the farmer's interest in adapting to use a smartphone and using it for various purposes, including obtaining agriculture-related information.

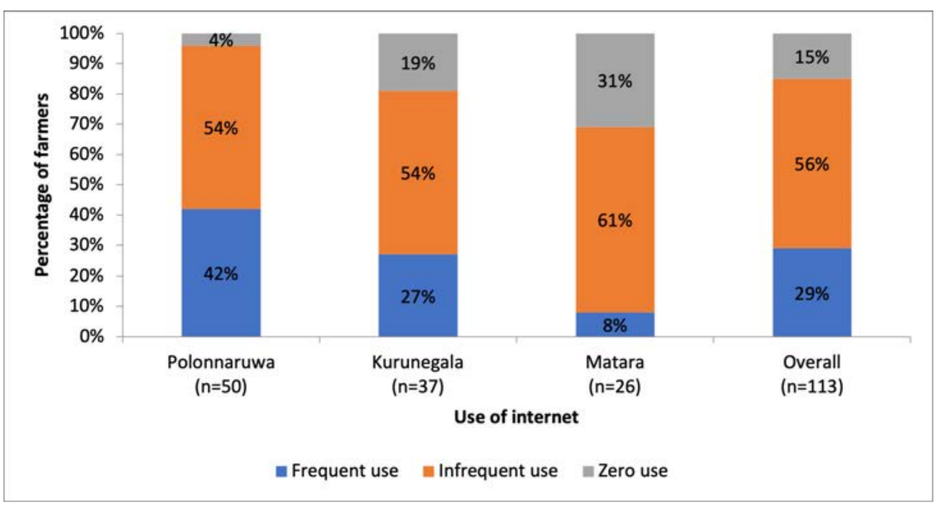


Figure 4.13 Frequency of internet use by sample farmers

Case Study: A farmer's experience of using a smartphone from Kurunegala district

> I started cultivating paddy at age 16. Initially, I had a feature phone and used it for a long period. If I remember correctly, in the year 2017, my elder son gave me his second-hand smartphone, so I gave my feature phone to my wife. Using a smartphone is an exciting experience, with many features such as a camera, video and radio. Initially, I faced many difficulties in handling the smartphone on various occasions. Once I was attending a farmer organization's meeting, the phone started to ring loudly, and I could not make it silent. Again, during the land preparation time, I missed several important calls because I keep the phone far away from the paddy field concerning its safety. Then, I decided to take the smartphone wherever I go and slowly managed to handle it without any problems. Now, I use it for varied purposes, and sometimes I use it to obtain agriculture-related information as well.

4.1.5 Awareness and use of mobile information for agricultural purposes

In recent times, many mobile-based novel extension approaches have been introduced in Sri Lanka by the government and many other authorities, including private entities, to target farming communities in particular. These approaches use mobile phones as a key mode of disseminating information, and they can be broadly categorized as mobile calls, mobile applications and mobile websites. Accordingly, the sample farmers were asked about their knowledge and use of agriculture-related mobile call services such as the 1920 call centre of the DOA, the 6666 Mobitel Agri-Price Information Index of HARTI and the 616 Dialog Govi Mithuru service. Fig. 4.14 illustrates the percentage distribution of farmers regarding their awareness and use of the above advisory services.

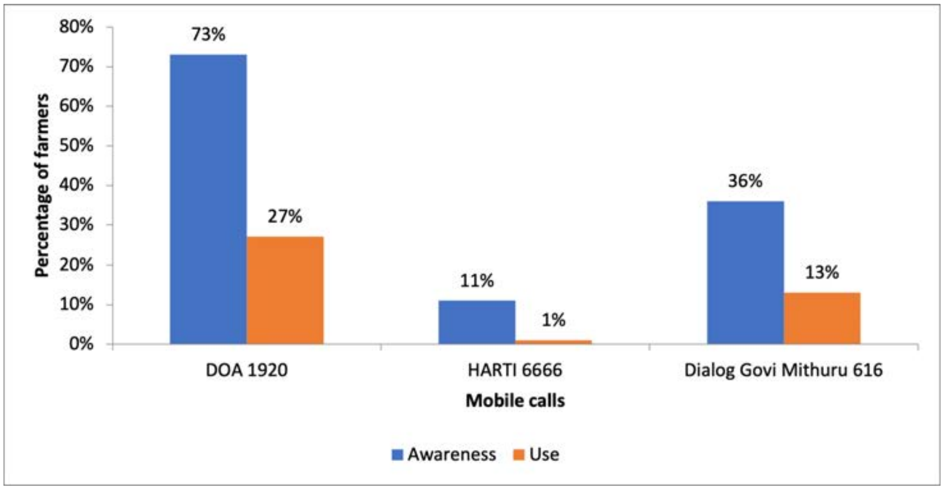


Figure 4.14 Awareness and use of farming-related mobile calls

As shown in Fig. 4.14, the DOA's 1920 call centre was the most popular advisory service used by the farmers, accounting for 73% of the sample. The DOA has regional offices all over the country, and this service has a considerably greater outreach than other call services because of the popularization of the service among the agricultural instructors. The call centre has a number of features, including personal assistance with live contact, a toll-free service, the possibility of repeated conversation with agricultural instructors, and wider accessibility from all mobile networks. However, around 27% of these farmers only sought assistance from the service once due to limitations such as inability of the agricultural instructors to respond to farmers' calls in a timely manner, and difficulty in interpreting information over the phone while following the advice. The Govi Mithuru advisory service was popular among 36% of the farmers, with approximately one-third having used the service only once. The HARTI 6666 daily price index was both the least known and least used. Upon further analyzing the reasons for farmers making mobile calls, the results presented in Fig. 4.15 revealed that the majority of the farmers (64%) had sought information on crop disorder management and technical support for crop cultivation (58%). Market and weather information was considered less critical to the farmers, whereas land-related information was a high priority.

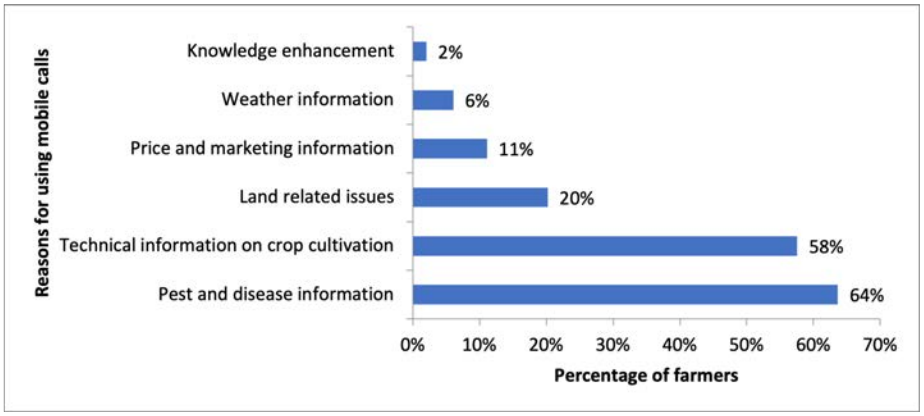


Figure 4.15 Reasons for making farming-related mobile calls

In terms of the awareness and use of mobile applications, the sample farmers were aware of several locally developed mobile applications by the government and other authorities, including private entities and a few applications developed internationally. Although the DOA predominates in developing agriculture-related mobile applications, there were eight applications being used by the farmers during the field survey. Hela Bojun and Govi Vedaduru were comparatively popular applications among the sample farmers. On the other hand, none of the farmers was aware of a few applications, such as Plant Treater and AIMS, which the DOA had introduced. Farmers were also poorly aware of the rest of the applications, whose usage was low, as indicated in Fig. 4.16. To a certain extent, the farmers knew mobile applications developed by private entities such as Govi Mithuru and Govipola; however, their usage was low. Globally accessible mobile applications such as Agrio, Sowing Calendar, Land Area and CF Calculator were used (or aware of) by less than 1% of the sample farmers. Fig. 4.17 illustrates the awareness and use of popular agriculture-related mobile applications by a number of farmers in the sample districts. A relatively higher number of farmers in Polonnaruwa were aware of the Govi Mithuru, Govipola, Hela Bojun and Govi Vedaduru applications, but the number of users remained low in other districts. Moreover, Fig. 4.18 shows that the farmers used mobile applications mainly to obtain information related to crop production and technical support (79%) and crop disorder management (43%).

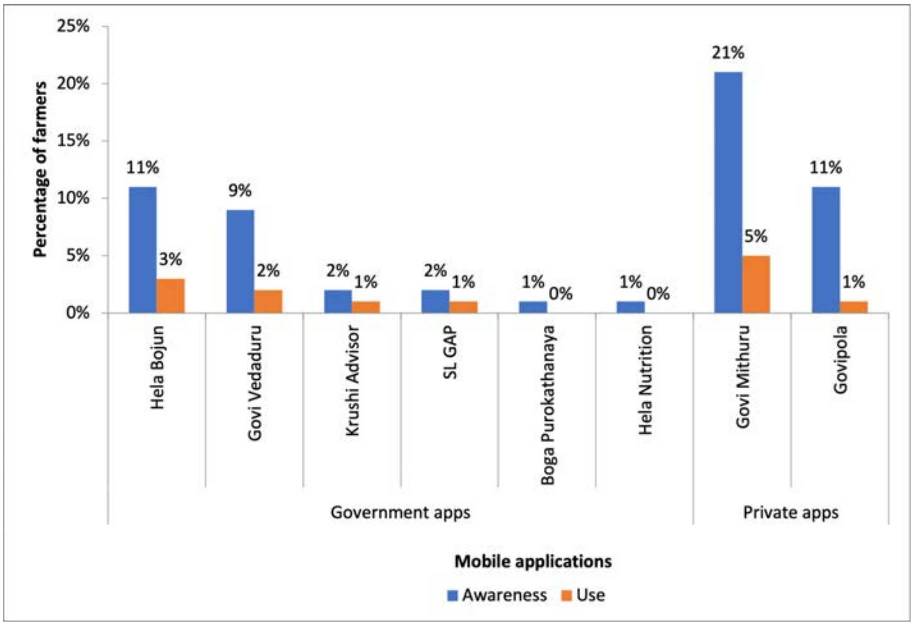


Figure 4.16 Awareness and use of agriculture-related mobile applications

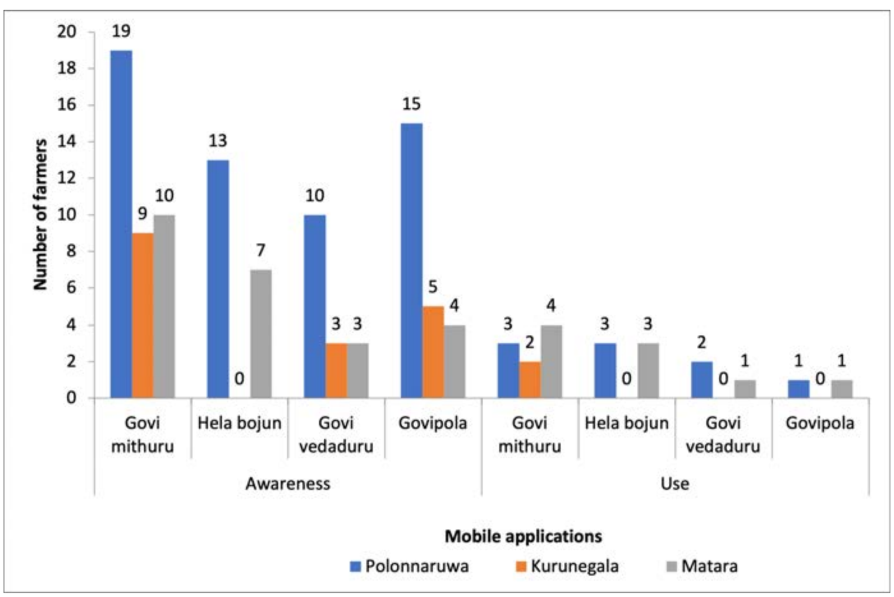


Figure 4.17 Awareness/use of agriculture mobile applications across districts

In terms of the awareness and use of mobile websites, only a small percentage of farmers used farming-related mobile websites, as per the results presented in Fig. 4.19. The DOA's website was the most browsed website by the sample farmers, accounting for 31% of awareness

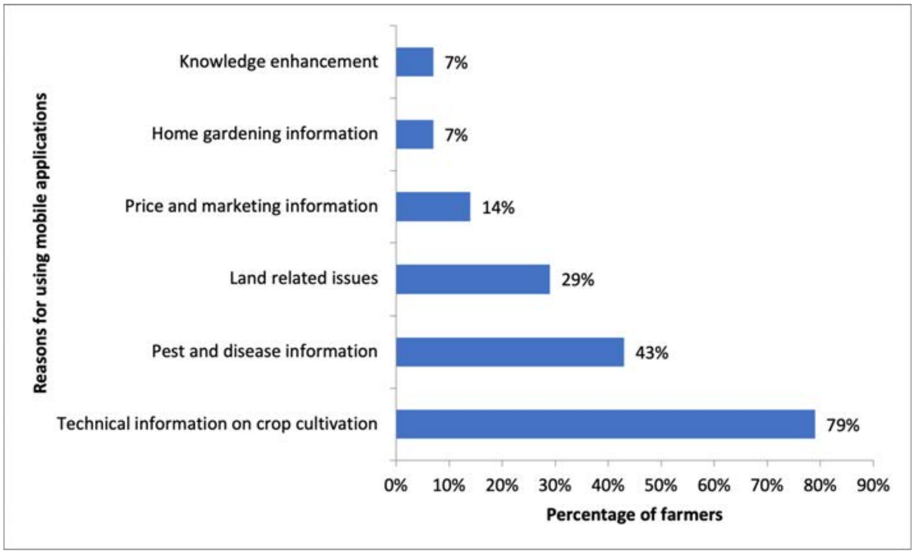


Figure 4.18 Reasons for using farming-related mobile applications

and 11% of use. In addition, agriculture-related YouTube channels (9%) and Facebook pages (3%) were used by some sample farmers. Upon analyzing the reasons for farmers using mobile websites, as presented in Fig. 4.20, the majority of farmers (94%) browsed websites to obtain technical information relating to crop cultivation, while 34% reported accessing information related to crop disorder management.

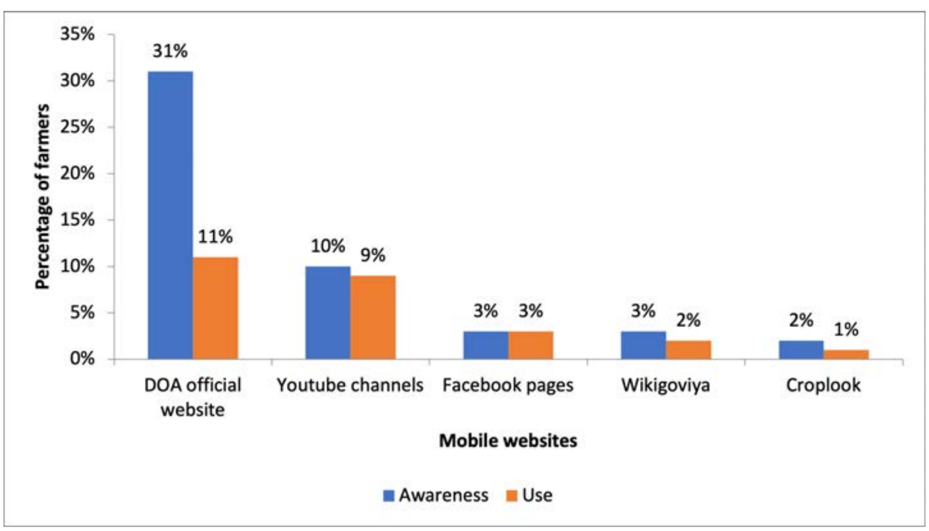


Figure 4.19 Awareness and use of agriculture-related mobile websites

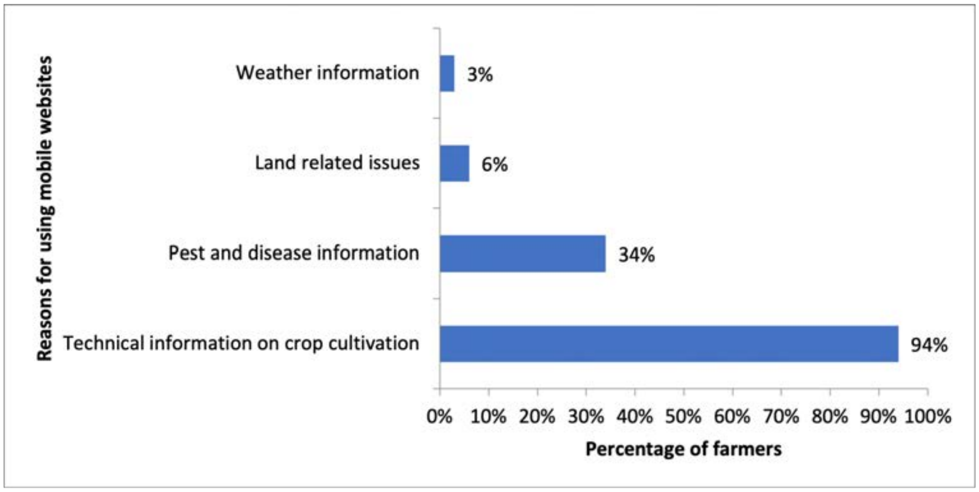


Figure 4.20 Reasons for using agriculture-related mobile websites

Even though farmers have a wider experience with respect to mobile phone usage, the level of awareness and use of farming-related mobile calls, applications and websites remained relatively low among the sample farmers. The reason for this has mainly been due to the difficulties of interpreting and following the provided information, and accessing the required information as quickly as possible, especially when managing crop disorder incidents. Moreover, farmers access such mobile-based services for various purposes; however, obtaining the information relevant to managing crop disorder incidents is considered as important as other general information needs. This indicates the need to obtain information linked to crop disorder management in an effective manner. Accordingly, we decided to develop a system facilitated by a mobile artifact as a potential intervention to address the various challenges associated with the crop disorder management process.

4.2 Understanding the persona and scenarios

Based on the findings and the nature of the study, a scenario-based approach was selected to come up with a list of requirements that need in-depth review to design robust a mobile artifact. A scenario-based approach is a powerful tool that supports the user-centred design of the solution to solve complex problems. Common activities in a scenario-based approach include creating personas and scenarios (Thimbleby, 2008). A persona is an abstract representation of the user for whom the artifact is designed. It consists of various properties of the user, such as age, social situation, education, family status and geographical location, and it can be used to derive the exact requirements, especially when they cannot be derived from users easily. Similarly, scenarios are related to the personas identified and the objectives or goals that personas would achieve (Peter, 2015). After identifying the personas and scenarios, a conceptual design and initial sketches/wireframes of the proposed artifact can be developed as required. Accordingly, the identified scenarios linked to a farmer persona is presented below:

Persona: Jayasiri

Jayasiri is a 40-year-old farmer with more than 20 years of experience in farming. Jayasiri lives in Nikaweratiya, a village in the Kurunegala district of Sri Lanka. He owns nearly five acres of farmland and cultivates paddy. He has a fundamental education level, having completed his GCE O/L, and could not study beyond that due to his involvement in farming from a young age. He has language barriers in understanding English; however, he has a basic understanding of using ICT tools—especially mobile phones. Jayasiri has a smartphone that he uses daily for various purposes, including contacting agricultural instructors to discuss farming-related matters, including managing crop disorder incidents. Jayasiri is the only person who manages the farm field, and sometimes he receives support from his neighbours if required.

Scenario: How does Jayasiri identify and manage crop disorder incidents?

In general, to identify the presence of crop disorders in the field, Jayasiri used to hunt for any abnormal symptoms or damage in the crops. Given his many years of experience in farming, most of the time, he can quickly recognize the cause of the damage present in his field and directly contact agrochemicals dealer shops to buy relevant agrochemicals to control the crop damage. However, Jayasiri sometimes applies an excess amount of agrichemicals due to his understanding that an excess amount of agrochemicals would be more effective without knowing the future consequences. Generally, he makes such decisions without consulting with subject experts due to the delays anticipated in contacting them and from fear of potential crop losses. There are also incidents that occurred when Jayasiri made the wrong choice of agrochemicals as a result of the misidentification of the crop disorders present in the field. Sometimes, if Jayasiri has difficulties in identifying the cause of the crop damage, he directly contacts agricultural instructors assigned to his village using his mobile phone. In general, to understand the ground situation in the field, the agricultural instructors ask Jayasiri a series of questions to determine the exact cause of the damage. These questions were mainly related to crop varieties, the crop's growth stage, affected part of the crop and the symptoms observed on the plant. However, it is sometimes difficult for agricultural instructors to correctly determine the cause of damage with the limited information provided by farmers like Jayasiri. In such cases, agricultural instructors ask for additional information such as agrochemicals or fertilizers employed previously, farming practices followed, weather conditions and many more. Moreover, before they conclude, they also ask farmers to send any image of the symptoms observed in the field to ensure they had correctly identified the cause. Based on that, the agricultural instructors advise farmers like Jayasiri of steps to follow to minimize crop damage and eliminate crop disorders. Unfortunately, there were also incidents that occurred when farmers like Jayasiri have misinterpreted the information provided by the agricultural instructors over the phone and made incorrect decisions, such as wrong agrochemical selection and incorrect handling of agrochemicals.

This exercise helped us to understand the important requirements of the problem area being investigated, and these requirements are given below:

- Among the challenges identified in the crop disorder identification process, farmers need to accurately capture measurements such as growth stages and symptoms present in the crop to identify the correct crop disorder. Henceforth, an effective way to capture the field observations must be investigated in the first instance, followed by crop disorder identification.

- Sometimes, due to the complicated behaviours associated with crop disorders and relevant field observations, the involvement of subject experts may be required to identify crop disorders manually. This will certainly result in loss of full automation; however, this may be necessary for the accurate identification of crop disorders.

- Farmers must be advised of the cause of the damage and the recommended control measures to be taken in a timely manner.

Chapter Five

Iteration 1: Evolution of the artifact

5.1 Conceptual Solution

Based on the requirements captured, a conceptual solution linked to the crop disorder management process was developed. This is presented in Fig. 5.1. The conceptual solution consists of three components, namely, symptom identification (A), crop disorder identification (B) and recommending control measures back to farmers (C). The identified components were further investigated to identify specific information needs, and these are detailed in the following sections. Initially, the study was designed to incorporate the information about the fully developed crop disorders; however, the proposed conceptual model could also be extended to include the information about the crop disorders that are in different development stages. Furthermore, the identified requirements were also used to populate a list of interface requirements for the end-users considering the usability of the solution.

5.1.1 Component A: Identification of field observations

As identified from the causal map depicted in Fig. 1.3, a crop disorder specific to a crop may manifest different symptoms depending on the growth stage of the crop, the development stage of the crop disorder, and where it is located in the crop, and notably, these symptoms

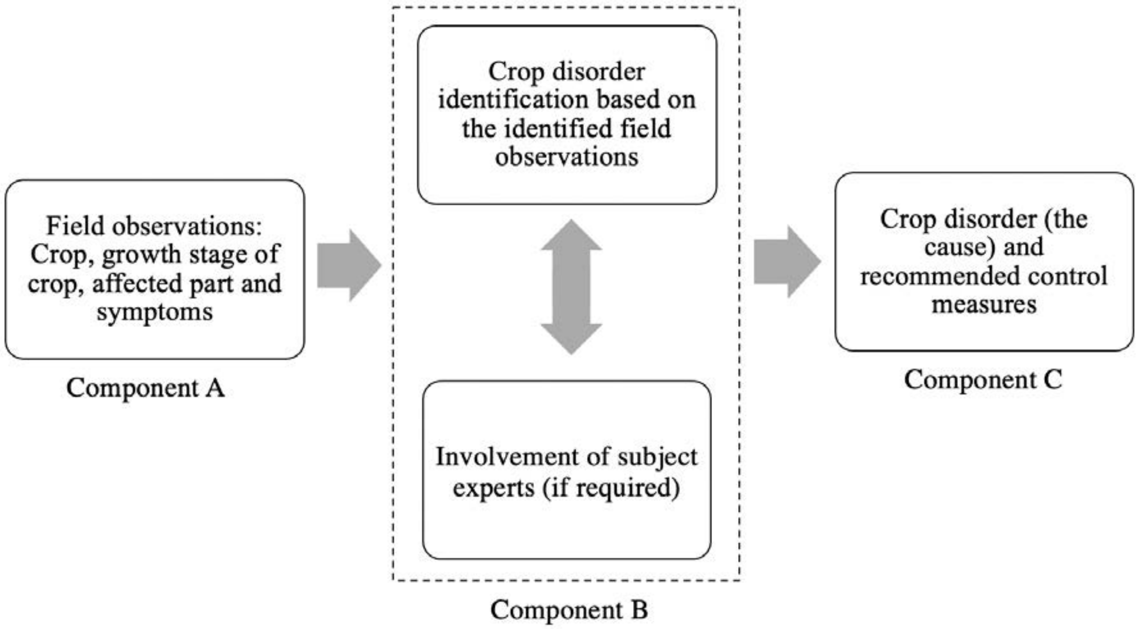


Figure 5.1 Conceptual solution proposed for crop disorder management process

have their own specific characteristics. Hence, reporting the correct symptoms observed in the field is vital for the reliable identification of crop disorders. Farmers play a major role in the crop disorder identification process as they are the ones who observe the field observations at the first instance. Given the many uncertainties involved in obtaining symptom-related field observations over the phone or as images, in this study, the researcher attempted to utilise the participation of farmers in a completely different way. Due to the complications associated with the appearance of symptoms on the plant, the lack of structured knowledge available to carry out the crop disorder identification and a way to capture symptoms from farmers effectively, the ADR team initially created a knowledge base of symptoms specific to a crop.

Here, the researcher introduces the concept of symptom class in streamlining the symptom identification process. The symptom classes can be defined based upon the characteristics of the symptoms of each crop disorder. For example, fully-developed rice blast disease in paddy (the crop is in the vegetative growth stage) expresses lesions with whitish centres with red margins on the leaves. Likewise, fully-developed bacteria leaf blight disease in paddy (the crop is in the vegetative growth stage) expresses a mix of yellow and orange color lesions. Even though the appearance of the above two symptoms is different, these two symptoms hold a common characteristic: lesion type symptoms. Hence, these two symptoms can be grouped as elements of a symptom class. This can be defined as *lesion* class. Another example is that the paddy exposed to Nitrogen deficiency manifests a symptom similar to folded leaves. At the same time, due to Calcium deficiency, the crop manifests curled leaves. Thus, the symptoms of folded leaves and curled leaves can be grouped as elements of another symptom class. This can be defined as *distorted leaves* class.

Sometimes, symptom classes may also hold some features attached to those. For example, the lesions of rice blast disease are spindle-shaped ones with a random appearance on the leaves. Similarly, the lesions of bacterial leaf blight disease are stripe-shaped ones with their appearance in the tip of the leaves. Based on this, the researcher found that lesion-type symptoms exhibit a set of class attributes such as the shape of the lesion, the lesion's distribution pattern, and the color of the lesion. Accordingly, the symptom class *lesion* that was defined earlier was extended to hold the above specific class attributes. As an example, the symptom class *lesion* of rice blast disease will have the values of the class attributes being, *shape: spindled-shaped*, *distribution pattern: random distribution* and *color: whitish centres with red margin*. Similarly, the symptom class *lesion* of bacterial leaf blight disease will have the values of the class attributes being, *shape: stripe-shaped*, *distribution pattern: tips of the leaves* and *color: mix of yellow and orange*. On the other hand, there are also symptom classes that do not hold any specific class attributes. For example, the symptom class *distorted leaves* holds different elements within that symptom class, such as folded leaves, curled leaves, elongated leaves and many others and notably, these distortion-type symptoms do not manifest any class attributes. Thus, class attributes are not required to be defined for this symptom class. Conclusively, class attributes are defined for a symptom class if that class manifests multiple features only (more than one attribute). The visualisation of the above findings is given in Fig. 5.2, and the image depicts a few of the symptoms that can be seen in paddy and how these symptoms are related to different symptom classes.

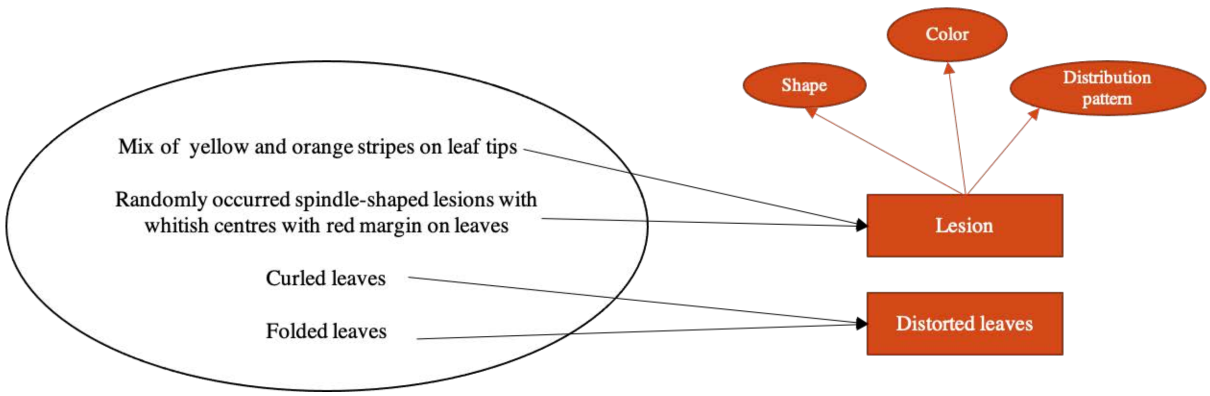


Figure 5.2 Association between symptoms and symptom classes for real-world scenarios

The generalised the relationship between symptoms and symptom classes of a crop as presented in Fig. 5.3. To illustrate this more, in the given figure, $s_1, s_2, ..., s_n$ represents symptoms, and each symptom belongs to a corresponding symptom class. Further, the symptom s_1 belongs to *Symptom class 1*, and *Symptom class 1* consists of two class attributes: *Attribute a* and *Attribute b*. Similarly, s_2 belongs to *Symptom class 2*, and this symptom class does not have any class attributes. Accordingly, with the help of subject experts, the researcher identified the possible symptom classes specific to paddy and the associated class attributes of the symptom classes (if they exist). This is followed by the symptoms manifested by the possible crop disorders in paddy were identified and assigned to the relevant symptom classes. Finally, the symptoms identified within the symptom classes were given identifiers in such a way to identify the symptoms within the symptom classes uniquely concerning different crop disorders. Table 5.1 and Table 5.2 list possible symptom classes identified for paddy, along with the associated class attributes and possible symptoms of each symptom class.

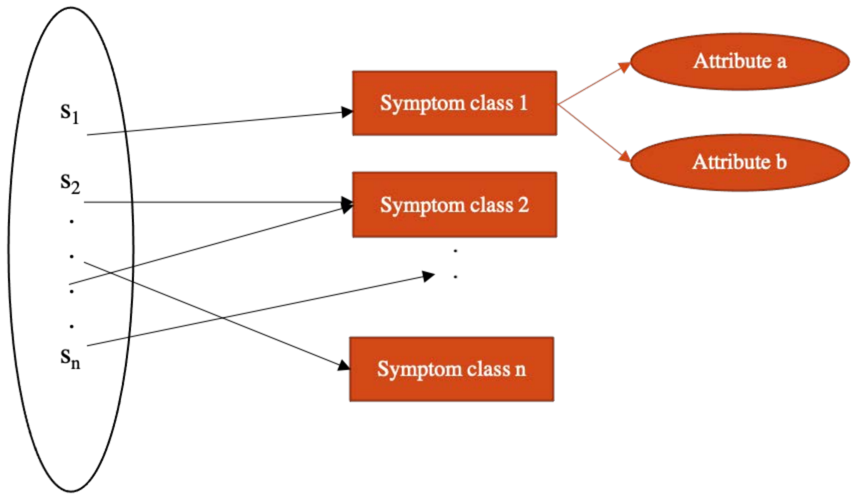


Figure 5.3 Association between Symptoms - Symptom classes

Symptom classes	**Symptoms**
A. Abnormal color	Yellowish green appearance (A1), Yellow appearance (A2), Brown appearance (A3), Black appearance (A4), Light Brown appearance (A5), Grey appearance (A6), White appearance (A7), Green appearance (A8)
B. Abnormal growth of plant	Stunted/short (B1), Bigger than normal (B2)
C. Cut stems/leaves	Irregular cut (C1), Cut at nodes (C2), Cut at 45 degree (C3), Cut at right angles (C4), Cut at seedlings (C5)
D. Bacteria ooze	Bacteria ooze come out (D1)
E. Dead plants	Fully dead plants (E1), Partially dead (E2)
F. Discoloration on seeds	Brown appearance (F1), Yellow appearance (F2), White appearance (F3), Black appearance (F4)
G. Abnormal grain production	Empty grains (G1), Partially filled grains (G2), Failed to produce grains (G3), Low quality grains (G4), Reduced grains (G5)

Table 5.1 Possible symptom classes, the class attributes and the relevant symptoms identified for paddy

Symptom classes		Symptoms
H. Fungal growth		Observable and sooty mold is present (H1), Observable and sooty mold is not present (H2)
I. Abnormal root growth		Enlarged (I1), Reduced (I2), Damaged roots (I3), Galls on roots (I4)
J. Appearance of excess instances		Spore instance (J1), Presence of velvety smut balls on spikelets (J2), Active burrows (J3), Footprints of rice field rats (J4), White powdery fungal growth (J5)
K. Webbing		White colored presence of webbing (K1)
L. Distorted leaves		Elongated (L1), Dropping (L2), Thin/narrow leaves (L3), Hollow tube look (L4), Curled (L5), Wider/big leaves (L6), Folded (L7), Dry leaves (L8), Crinkled leaves (L9), Tiny holes (L10)
M. Lesion	M1. Color	Brown appearance (M1-1), Yellow-Orange appearance (M1-2), White appearance (M1-3), Whitish to gray centers with red to brownish border (M1-4)
	M2. Shape	Spindle-shaped (M2-1), Linear (M2-2), Spots (M2-3), Circular Irregular or oblong patch (M2-4), Oval (M2-5), Streaks (M2-6), Stripes (M2-7)
	M3. Dist. pattern	Tips of the part (M3-1), Side of the part (M3-2), Middle part (M3-3), Parallel to vein (M3-4), Uppermost part (M3-5), Random (M3-6)
N. Wilting		Observable and plant can be easily pulled out (N1), Observable and plant cannot be easily pulled out (N2)
O. Tillering		Excessive (O1), Reduced (O2), Re-tillering (O3)
P. Chlorosis		Severely occurred (P1), Moderately occurred (P2), Randomly Occurred (P3)
Q. Dead hearts		Severely occurred (Q1), Moderately occurred (Q2), Randomly Occurred (Q3)

Table 5.2 Possible symptom classes, the class attributes and the relevant symptoms identified for paddy continued.

5.1.2 Component B: Crop disorder identification

Based on the generalized relationship presented in Fig. 5.3, a crop disorder may be linked to many symptom classes, and at the same time, a symptom class will become relevant to many crop disorders. Similarly, as discussed, crop disorders manifest different symptoms depending on varied factors such as the growth stage of the crop, development stage of the crop disorder and affected part in the crop. According to the above characteristics identified, a structure was proposed by the researcher as given in Table 5.3, that captures the overall mapping of the identified properties in the crop disorder identification process. The proposed structure consists of the following properties;

- Crop disorders that affect a crop varies according to the growth stages of the crop. Thus, different structures will be produced for different growth stages of the crop.
- A column dimension named "Crop disorder" was defined to list crop disorders. Thus, for each new crop disorder, a new record will be inserted in the proposed structure.
- A column dimension named "Affected part" was defined to store the part of the crop that gets affected by the corresponding crop disorder. Thus, a crop disorder that may affect multiple parts of a plant will have multiple records in the proposed structure.
- If a crop disorder gets related to a symptom class, then the suitable symptom from that symptom class will be stored in a column dimension named "Relevant symptoms". The information within this dimension will be stored as *symptom class ->symptom*. On the other hand, if a crop disorder does not manifest any symptoms from a symptom class, then that information will not be stored, as crop disorder manifests symptoms only with respect to some symptom classes only.
- Only the crop disorders that are in the matured development stage were considered in this research. However, a new column dimension can be included to store the development stage of the crop disorder by extending the proposed structure.

As per the generalized structure presented in Table 5.3, for this research purpose, the above structure was customized to keep the information about paddy (multiple search spaces for different growth stages of paddy) with values for rows being possible crop disorders and columns being the part of the crop that gets affected by the crop disorder and the suitable symptom from the identified symptom classes. An example is presented in Table 5.4 that depicts the proposed structure customized for paddy with information of a few crop disorders (crop is in the vegetative growth stage).

Crop disorder	**Affected part**	**Relevant Symptoms**
Crop disorder 1	Part 1	Class A ->Symptom 1, Class B ->Symptom 2
Crop disorder 2	Part 2	Class A ->Symptom 3, Class C ->Symptom 1, Class D ->Symptom 1
Crop disorder 3	Part 1	Class A ->Symptom 2, Class D ->Symptom 1
Crop disorder 3	Part 3	Class P ->Symptom 1, Class Q ->Symptom 1
……	……	……
……	……	……

Table 5.3 A generalised structure for a crop to store the identified mappings in the crop disorder identification process

Crop disorder	**Affected part**	**Relevant symptoms from the identified symptom classes**
Rice blast	Leaves	{E ->E2}, {M ->M1-4, M2-1, M3-6}
Thrips	Leaves	{E ->E2}, {L ->L4}, {M ->M1-3, M2-6, M3-4}
Stem borer	Stem	{L ->L10}, {K ->K1}, {N ->N1}, {Q ->Q1}
Bacterial leaf blight	Leaves	{D ->D1}, {M ->M1-2, M2-7, M3-1}, {N ->N1}
…..	…..	…..

Table 5.4 A structure for paddy to store the identified mappings in the crop disorder identification process

The proposed structure can also be regarded as a crop disorder search space of a crop that is in a specific growth stage. To perform the search operation on the crop disorder search space, the information related to the crop, growth stage of the crop, affected part in the crop, and the symptom observed in the field must be captured from farmers. In addition, once the search space was fully populated for paddy, it was also found that,

- one symptom from a specific symptom class or
- a combination of some symptoms from different symptom classes would provide a unique identification property particular to a crop disorder.

For example, Rice Blast disease in paddy manifests spindled-shape lesions with whitish to grey centres and red to brownish margins; this symptom is unique to Rice Blast and can distinguish it from other crop disorders. Hence, it is not necessary to consider all the symptoms identified specific to a crop disorder; instead, the symptom(s) with the unique identification property would be sufficient to determine the crop disorder. Similarly, there are also crop disorders identified in the search space, with the symptoms of those not manifesting any unique identification property. The overall observation with respect to the identified property is presented in Fig. 5.4. An example is also given in Table 5.5, which depicts the symptoms of crop disorders with the identified property in paddy as red-coloured text. Therefore, providing farmers with a list of symptom(s) with unique identification properties and getting a confirmation for the presence of such symptom(s) will result in the identification of relevant crop disorders. Notably, the effort required to identify the crop disorders from larger possibilities was also drastically minimised.

Thus, to perform the search operation on the crop disorder search space and to obtain the symptom(s) that provide a unique identification property from farmers, the relevant symptom(s) with a unique identification property of crop disorders were converted to form a meaningful textual representation. The outcome was regarded as the “disorder identifiers” of the corresponding crop disorders, and the structure proposed earlier was extended to include

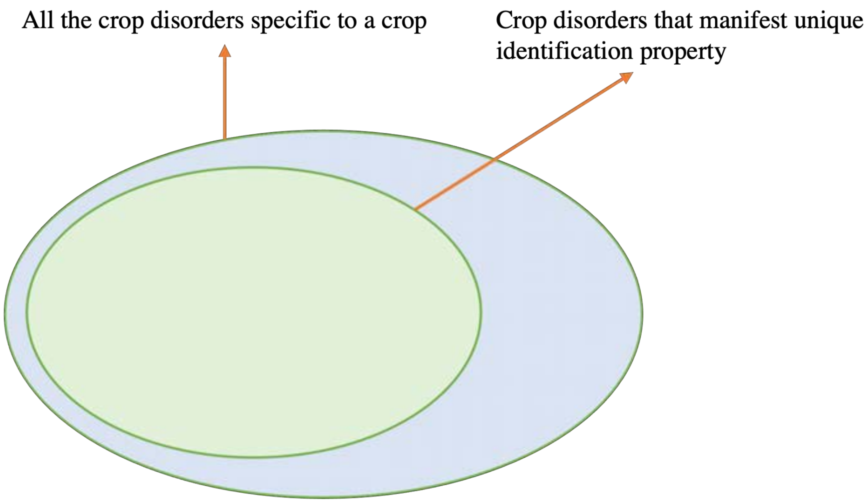


Figure 5.4 Observation found with respect to the unique identification property of crop disorders in the crop disorder search space

Crop disorder	**Affected part**	**Relevant symptoms from the identified symptom classes**
Rice blast	Leaves	{E ->E2}, **{M ->M1-4, M2-1, M3-6}**
Thrips	Leaves	{E ->E2}, **{L ->L4}, {M ->M1-3, M2-6, M3-4}**
Stem borer	Stem	{L ->L10}, {K ->K1}, {N ->N1}, {Q ->Q1}
Bacterial leaf blight	Leaves	{D ->D1}, **{M ->M1-2, M2-7, M3-1}**, {N ->N1}
.....	.....	.....

Table 5.5 Symptoms of a few crop disorders with unique identification property (as shown in Red-coloured text)

a new column dimension named "disorder identifier". As an example, the disorder identifiers of different crop disorders in paddy (growth stage of paddy is vegetative) is presented in Table 5.6. Similarly, if the symptoms of a crop disorder do not have any unique identification property, then the cell value of the "disorder identifier" of that crop disorder would be blank. With this approach, the overall process of identifying crop disorders was simplified as the correct selection of the disorder identifier based on the field observations spontaneously results in the relevant crop disorder.

Crop disorder	**Affected part**	**Relevant symptoms**	**Disorder identifier**
Rice blast	Leaves	{E ->E2}, **{M ->M1-4, M2-1, M3-6}**	Spindle-shaped lesions with whitish to gray centers and red to brownish margin on leaves
Thrips	Leaves	{E ->E2}, **{L ->L4}**, **{M ->M1-3, M2-6, M3-4}**	Leaves curled to the middle with white streaks parallel to vein
Stem borer	Stem	{L ->L10}, {K ->K1}, {N ->N1}, {Q ->Q1}	
Bacterial leaf blight	Leaves	{D ->D1}, {N ->N1}, **{M ->M1-2, M2-7, M3-1}**	Yellow-Orange color stripes on leaf blades or leaf tips
.....	.....	.....	.....

Table 5.6 Extended crop disorder search space with corresponding unique identifiers

From a technical perspective, empowering farmers to report the correct disorder identifier based on their field observations and identifying the relevant crop disorders largely addresses the overall challenges identified in the crop disorder identification process. However, on the other hand, if no relevant disorder identifier is chosen when comparing with the field observations, the instant identification of the crop disorders becomes impossible. Thus, the manual involvement of the subject experts such as agricultural instructors, agriculture researchers, entomologists and pathologists was sought to figure out the exact cause by interacting with the farmers. Again, with this scenario, the proposed structure can be a useful tool to assist the subject experts in initiating relevant discussions with farmers or instantly eliminating the irrelevant possibilities, as the knowledge required to identify relevant crop disorders from field observations is appropriately structured. The overall search logic used to reduce the crop disorder search space is depicted in Fig. 5.5. Sometimes, there can be situations where more than one part of the plant gets affected, or concurrent crop disorders may present in the plant. If so, farmers must select the relevant choices concerning the severity of the symptoms that appear on the plant. Notably, the proposed structure has also capable of scaling to accommodate new requirements. For example, information about new crop disorders or new symptoms can be easily added to the existing search space.

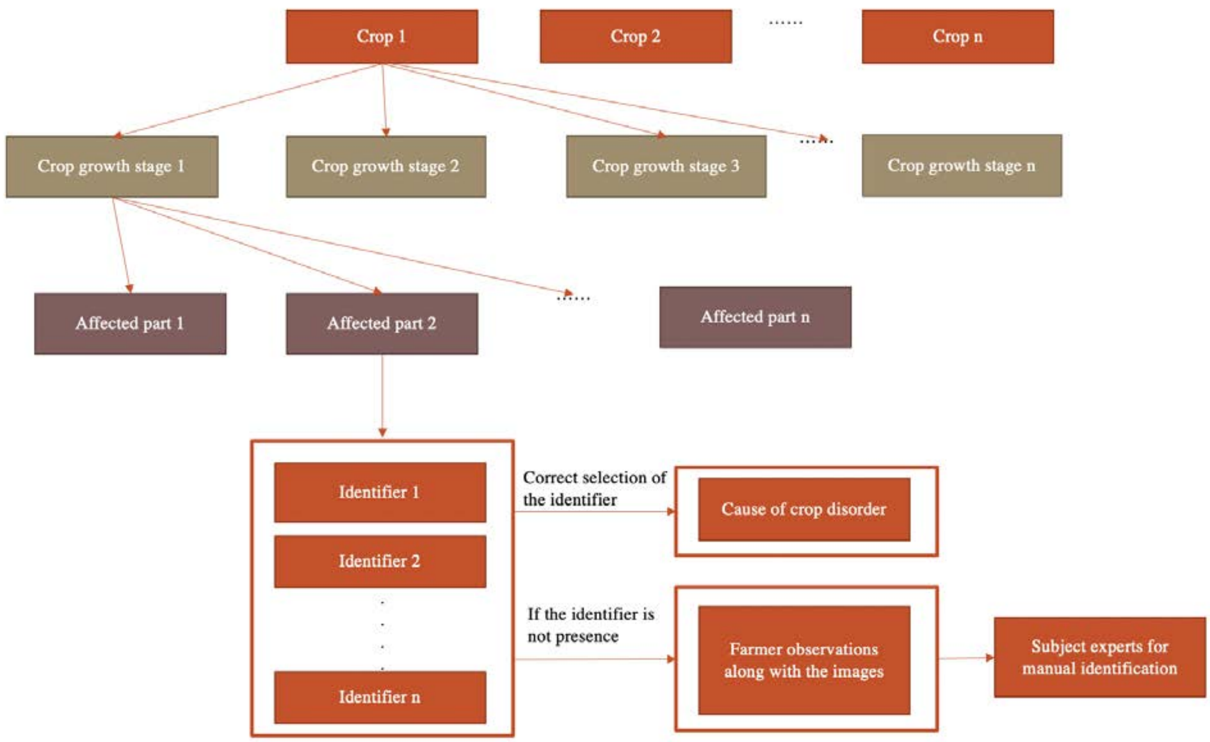


Figure 5.5 Search logic used in the proposed structure to identify crop disorders

5.1.3 Component C: Recommendation of control measures

The next step was to link recommended control measures to relevant crop disorders considering the current limitations associated with agrochemical handling of farmers, as discussed in Chapter 1. As a possible solution, the knowledge relevant to different control measures, namely, cultural, biological, mechanical and chemical and the corresponding application instructions were appropriately structured in a way that assist farmers in prompt decision-making. Further, to prevent the field from likely crop disorders in future, preventive control measures are also needed. Thus, the information about various preventive control measures of crop disorders was also included while providing the control measures. Providing farmers with such enriched information helps them adhere to recommended control measures to manage crop disorders and, at the same time, help to safeguard the crops from likely crop disorders in the future. Table 5.7 abstracts different types of control measures and the associated recommendations considered with each type in the proposed artifact .

Control measure types	**Recommendations considered**
Cultural method	Adjust planting location, adjust timing intervals between activities, crop rotation, watering and fertilizing, growing competitive plants, and change cultivation techniques
Physical method	Place barriers and traps, physically remove affected plants, vacuum, heat treatments, and mowing
Biological method	Use of predators, parasites or microbial pathogens, encourage natural enemies by planting specific plants
Chemical method	Use of toxic-chemical substances along with the recommended dosage level, chemical handling and application instructions

Table 5.7 Recommendations considered in the proposed artifact

5.2 Evolution of the artifact

As per the conclusion derived from the baseline study, the researcher chose to implement a mobile artifact as the potential tool for managing crop disorder incidents. Accordingly, the researcher decided to develop two stand-alone mobile artifacts for both farmers and the subject experts (e.g., agricultural instructors, pathologists, and entomologists). The mobile artifact for farmers will allow them to access crop disorder management services in real-time by reporting crop disorder incidents observed in the field and instantly receiving advice regarding remedial actions.

Alternatively, if the field is affected by a crop disorder that is not included in the provided list of disorder identifiers, or if the provided information is hard to interpret, then it requires subject experts to identify the crop disorders. Thus, an interaction between the farmers and the subject experts is a crucial requirement. Hence, to serve this purpose, the second mobile artifact was developed for the subject experts to communicate with farmers and to identify crop disorders. This was achieved through establishing a two-way communication channel similar to instant messaging systems in the mobile applications.

The application of mobile technology in the crop disorder management process is a relatively new concept to farmers. Hence, it was identified that the mobile interfaces should be appropriately and carefully designed. Accordingly, the researcher mapped the overall design features of the proposed solution to separate screens and created an initial set of mobile interfaces. The user cases, user actions and corresponding system responses were also considered while developing the mobile interfaces. Then, the mobile interfaces were shared with the agriculture subject experts within the ADR team to assess those concerning the elements included in the interfaces and their placement on the screen, color selection, missing functionality and overall simplicity. The initial mobile interfaces gave them an idea of how information flows within the proposed system, which enables farmers to make the best use of the available screen area and effectively capture the required input. Throughout this research study, the researcher and others in the ADR team collaborated closely in all activities resulted in the requirements being fully captured and implemented during the initial mobile interface development itself, and there were no significant modifications suggested to the developed mobile interfaces. In addition, the information flow between different interfaces of the proposed solution was categorized into three groups based on their features. A detailed description of the information flow is discussed in the next section.

5.3 Development of the artifact

The mobile interfaces in group one, which are presented in Fig. 5.6, describe the overall information flow related to farmers registering farms and adding crop varieties to their farm based on their preferences. After registering a farm on screen B of Fig. 5.6, the crop list screen displays all of the crops and the varieties available for the selected farm (based on the geographical region) and the selected season, as on screen C of Fig. 5.6. Depending on the characteristics of the crop varieties as presented on screen D of Fig. 5.6, farmers can select the crop varieties they prefer to grow and set the planting date for each crop variety chosen, as on screen E of Fig. 5.6. From a technical perspective, information such as crop and the variety being selected to grow, farm location, planting date, and season will be captured as a result of the user actions undertaken on the developed mobile interfaces in group one. Moreover, such information will be used to satisfy the information needs in other interfaces as presented in Fig. 5.7 and Fig. 5.8.

The mobile interfaces in group two, which are presented in Fig. 5.7 represent the highlighted feature of the proposed solution and depict the information flow with respect to capturing field observations from farmers. The system generates a series of inbuilt selections based on the chosen crop and crop variety as part of the crop disorder identification process. Accordingly, these inbuilt selections were identified as the plant's growth stage, the affected part of the plant, and the observed disorder identifier. Here, a choice with respect to a mobile interface farmer selects would generate dynamic selection choices in the following mobile interfaces. When farmer selections are completed, the choices made by farmers will be used to find the relevant crop disorder from the crop disorder search space. Notably, the given choices as a list disorder identifiers also make the user comfortable selecting the right choice as they represent a unique and consistent depiction of the presence of relevant crop disorders. Since these disorder identifiers are already linked to corresponding crop disorders and control measures in the back end, the correct selection of the disorder identifier from the list as in Screen B of Fig. 5.7 exposes the user to know the exact crop disorder present in the field and relevant control measures. The format of the control measures related to the identified crop disorder is presented in screen C of Fig. 5.7. The information such as a short description about the crop disorder and relevant control measures, including cultural, biological, mechanical and chemical, along with the relevant application instructions and preventive control measures, was included as part of the response back to farmers.

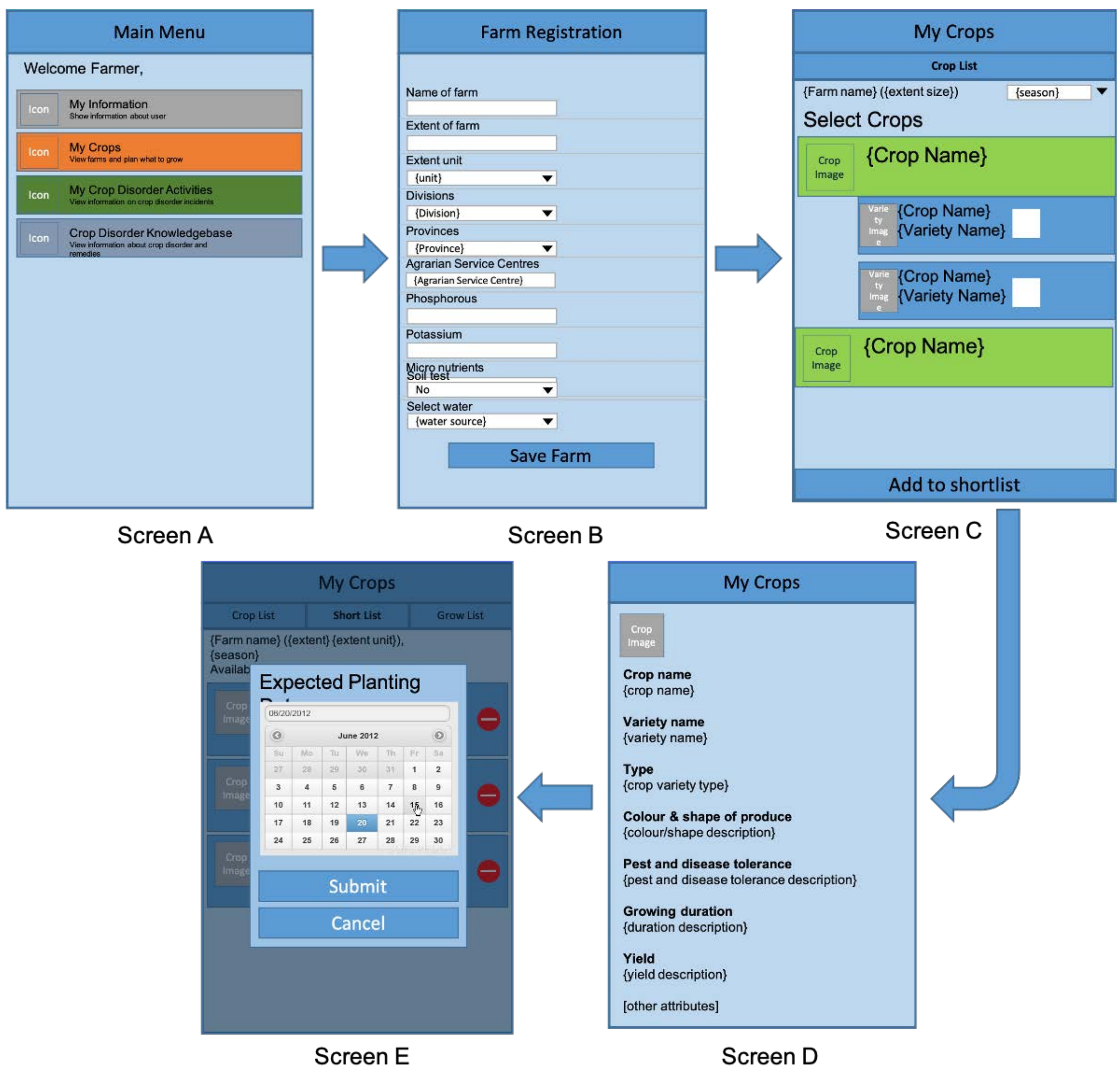


Figure 5.6 Group one: information flow related to selection of crop varieties

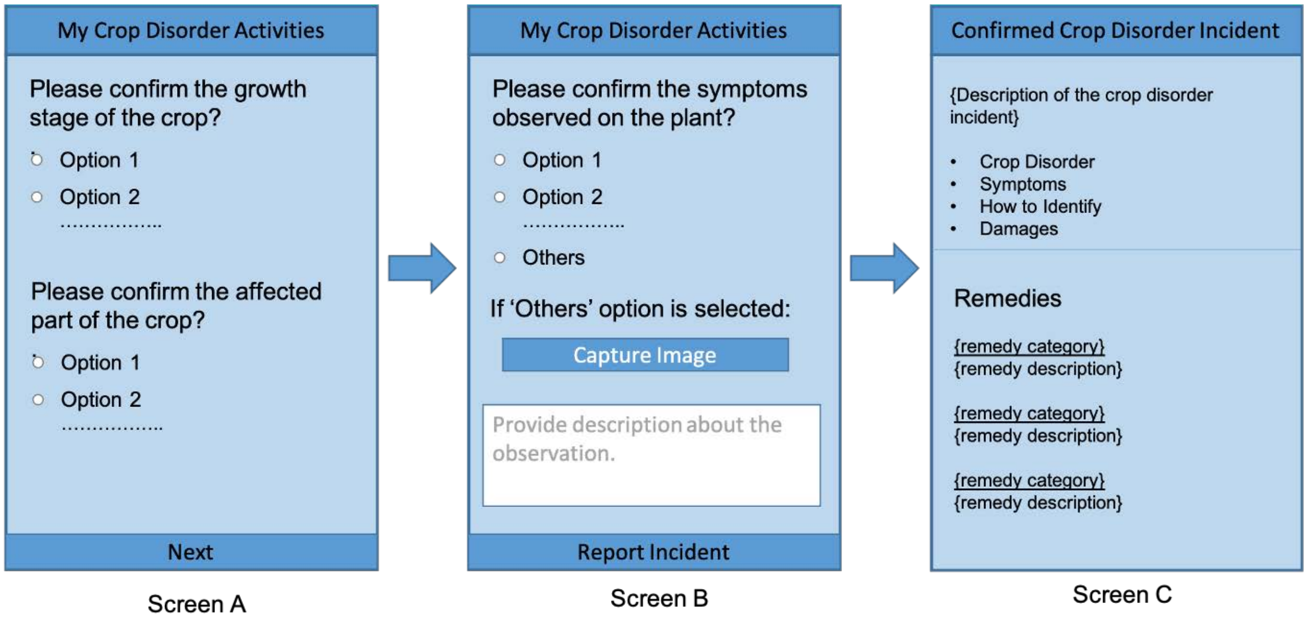


Figure 5.7 Group two: information flow related to reporting crop disorder incidents

Finally, the mobile interfaces in group three, which are presented in Fig. 5.8, represent the information flow related to the manual identification of the crop disorder incidents by the subject experts. If the farmer does not find a suitable choice from the given list of disorder identifiers (see screen B of Fig. 5.7) or having difficulties in selecting a matching identifier compared with their actual field observations; in that case, the farmer can input the information related to their field-observations to the system for the subject experts to do the manual identification (see the bottom part of screen B of Fig. 5.7). Here, farmers were also compelled to attach images of their field observations in addition to the other selections. As the next step, the reported incidents will be presented to the subject experts through the mobile artifact developed for them (see screen A of Fig. 5.8). To assist subject experts in their decision-making, the following information such as crop and variety, the growth stage of the crop, affected part, their field observations and images were made available as a result of the user actions (see screen B of Fig. 5.8).

Accordingly, the subject experts can;

- decide on the relevant crop disorder based on the available information
- ask the farmers questions to understand more about the field situation to obtain more clarity and reduce the possibility of misidentifying the problem.

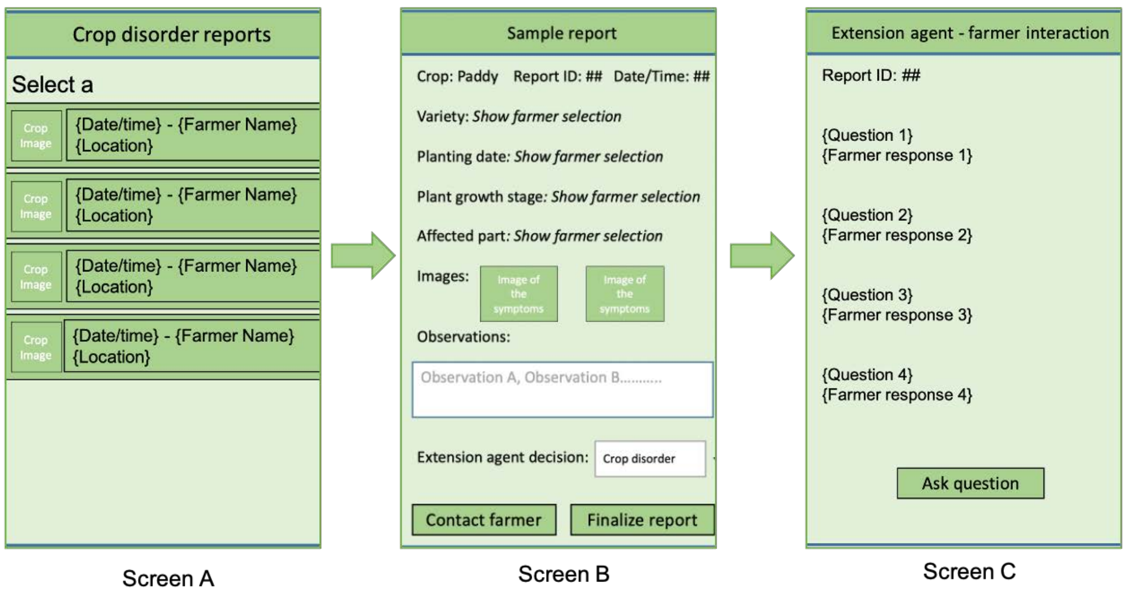


Figure 5.8 Group three: information flow related to manual identification of crop disorders by subject experts

To facilitate this purpose, a two-way communication channel was created to assist the subject experts to interact with the farmers to obtain additional information to identify crop disorders correctly. Accordingly, based on the farmers' responses to the queries raised (see screen C of Fig. 5.8), the subject experts can eliminate irrelevant possibilities and decide on the suitable crop disorder. Finally, upon subject experts confirming the relevant crop disorders, the farmers will get the corresponding control measures similar to as shown in screen C of Fig. 5.7. The implementation of the working artifact from the mobile interfaces as discussed in groups one, two and three are presented in Fig. 5.9, Fig. 5.10, and Fig. 5.11. In Fig. 5.11, the interfaces related to the dashboard of the subject experts are grouped within the red-dashed line. Moreover, it is also important to present the information in their local language. Thus, the artifact was customized to support their language needs as well.

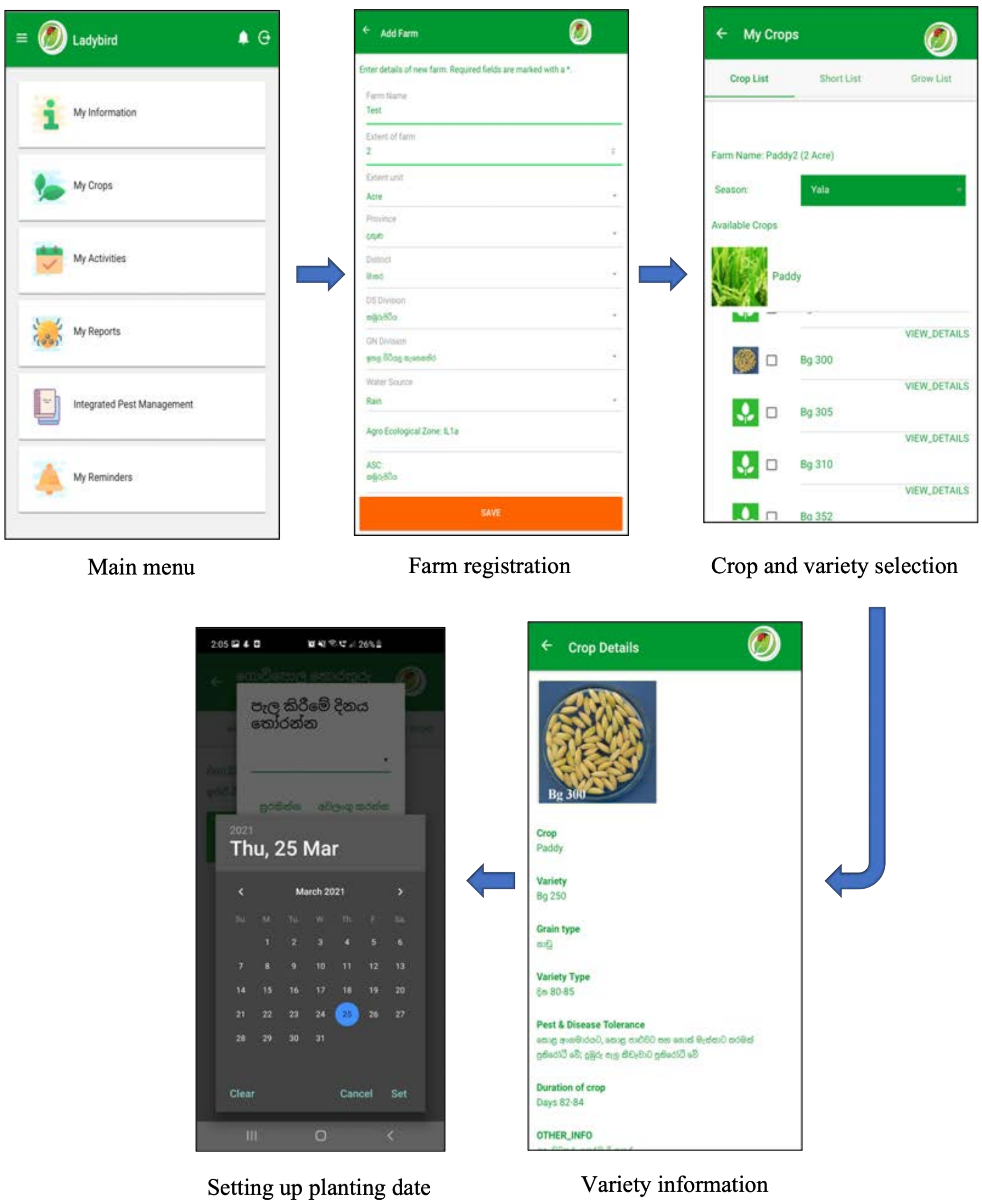


Figure 5.9 Implementation of the working artifact from the interfaces presented in group one

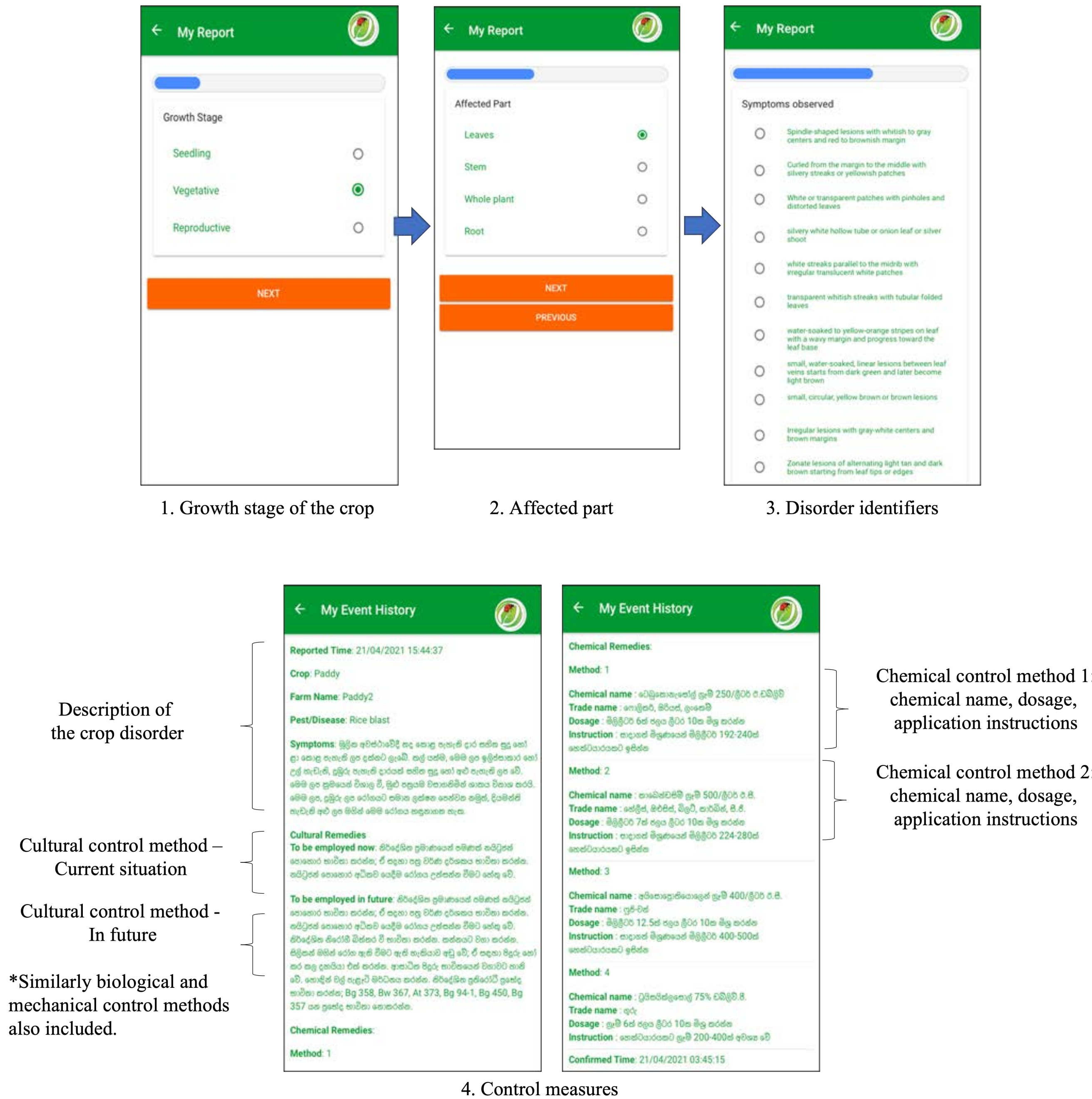


Figure 5.10 Implementation of the working artifact from the interfaces presented in group two

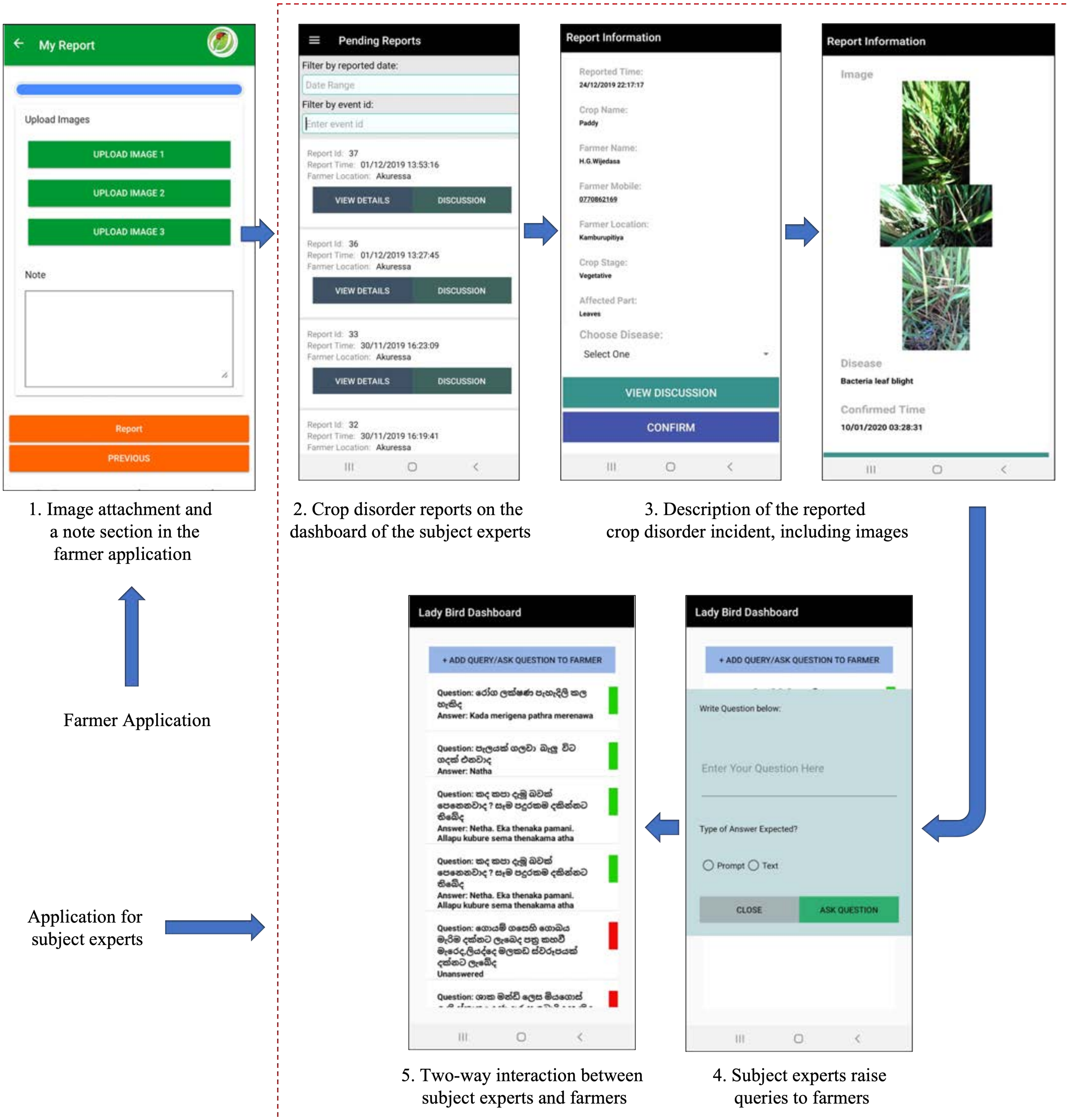


Figure 5.11 Implementation of the working artifact from the interfaces presented in group three

5.4 Deployment of the developed solution

Regarding deploying the solution, the ADR team visited the identified study locations and organized individual and group discussion sessions to assist farmers with installing the artifact on their mobiles and provide relevant technical training on how to operate the proposed artifact . Accordingly, the 180 farmers from the three study locations were individually requested to attend the sessions. However, at the time of the deployment, the research team encountered a few challenges that led to failures in installing the solution on farmers' mobile phones and difficulties in contacting them as per the deployment plan. These challenges are detailed in this upcoming section. As a result, some of the participants were not able to participate in trialling the solution. Henceforth, to balance the deviation from the initial participants, the researcher decided to increase the sample size. The updated participants' detail is presented in Table 5.8.

District	Baseline Sample	New Sample	Deployment Sample
Polonnaruwa	60	71	37
Kurunegala	60	74	39
Matara	60	61	40
Total	180	206	116

Table 5.8 Number of baseline, new and deployment sample farmers

The deployment activities began in the Matara district, followed by Kurunegala and Polonnaruwa, and the team managed to install the developed artifact on the mobile phones of 116 farmers from the new sample. The deployment activities continued for almost nine weeks, from 2 December 2019 to 2 February 2020. The number of weekly installations performed by the ADR team is shown in Fig. 5.12. Interestingly, it took almost seven weeks to cover the first half of the deployed sample, while the other half was covered in just two weeks, showing the success of the deployment in Polonnaruwa as a result of the lessons learnt from the deployment in Matara and Kurunegala.

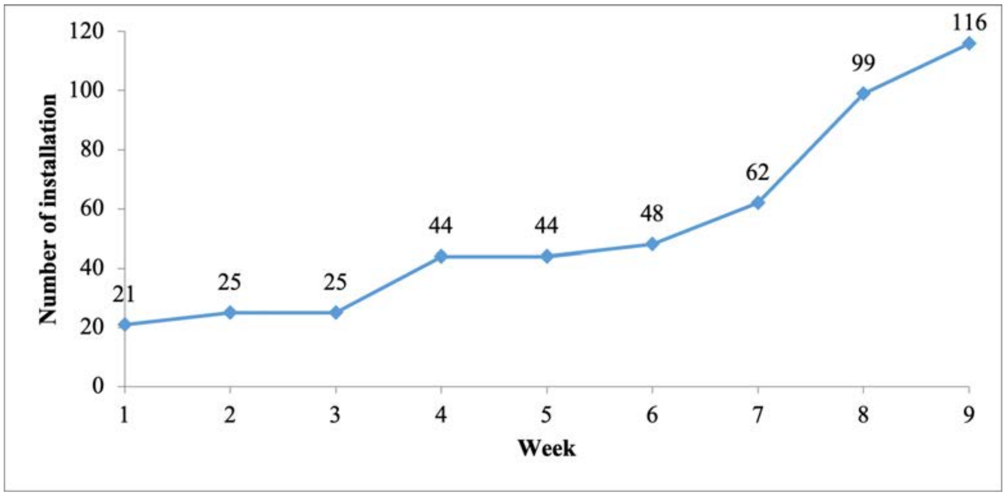


Figure 5.12 Number of installation of the mobile artifact by week

As briefly discussed earlier, although the total number of participants in the new sample was increased to 206, only 116 farmers (about 56%) were able to successfully install the artifact on their mobile phones. The remaining 90 farmers faced installation failure for various reasons, which are outlined in Fig. 5.13. Android-compatible devices and devices with minimum Android version (version 6.0) were essential requirements for running the artifact successfully. However, nearly 6% of the farmers were dropped from the sample at the deployment stage due to them owning mobile phones with different operating systems (e.g., iOS and Windows). Further, 36% of farmers had an incompatible version of Android on their phones. Although the farmers had smartphones, many of them owned smartphones with older versions of Android, which were not compatible with the minimum specification requirements of the developed solution.

Moreover, internet connectivity is essential for installing and using the artifact , and 3% of installation failures were associated with poor internet signal strength. In addition, farmers who did not have their smartphone with them at the time of deployment or had a broken phone accounted for 14% of installation failures. Inaccessible farmers were also a significant factor contributing to the failure to install the artifact on farmers' mobiles, accounting for 41%. Inaccessible farmers were those who were initially selected at the baseline survey study but were inaccessible during deployment because they had not attended the training sessions or they had moved out of the area, were unavailable during the personal visit or were unable to be contacted.

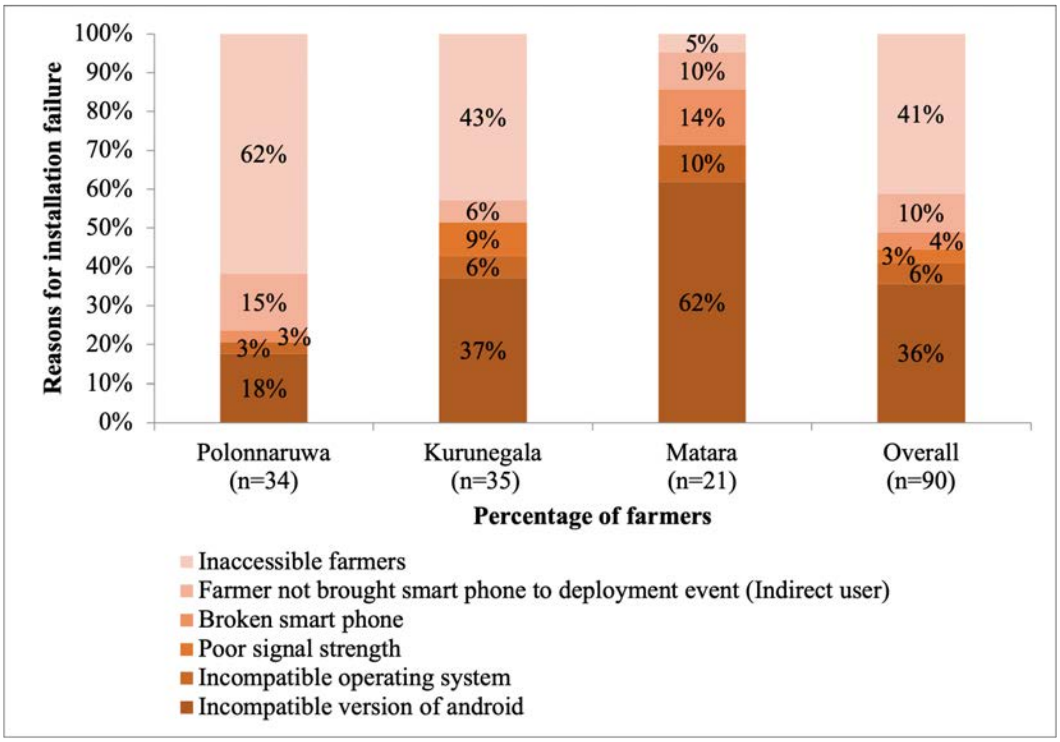


Figure 5.13 Percentage distribution of reasons for installation failure across districts

In Matara, the solution was initially introduced to farmers through two focus group discussions hosted at the two identified agrarian service centres (ASCs) located in Matara, namely Kamburupitiya and Akuressa. Further, the farmers who could not attend the first two sessions were individually contacted to introduce the artifact to them. As a result, the rate of inaccessibility was only 5% in Matara. Similar to Matara, two training visits were organized in Kurunegala, and only a few of the remaining farmers who were unable to attend were approached individually. However, the rate of inaccessibility was high, accounting for

43%. In Polonnaruwa, similar to the other two study locations, two training sessions were organized to introduce the mobile artifact to farmers, and no farmers had to be reached individually, leading to an inaccessibility rate of 62%. From the approach employed by the ADR team while deploying the mobile artifact on farmers' mobiles, it was evident that the individual approach was better to reach many farmers, but it was not practically feasible when time and cost factors were considered. Moreover, based on discussions with farmers and agricultural instructors in the identified study locations, it was also revealed that the reduced attendance of farmers was primarily due to their busy schedules, as well as the distance they had to travel to attend the training sessions.

5.5 Results and Evaluation

At the end of the trial period, the researcher performed a number of experiments to assess the effectiveness and usability aspects of the solution to determine whether the on-the-ground situation had improved, especially in relation to managing crop disorder incidents. Despite farmers faced many technical challenges in the deployment stage, it was observed that the farmers in the sample had actively started using the artifact and participated in reporting crop disorder incidents. Moreover, the farmers' enthusiasm and motivation in using the artifact to report crop disorder incidents reflect their readiness in accepting technology-based interventions. Fig. 5.14 presents the overall crop disorder incidents reported by farmers each week during the 2019/20 Maha season from 2 December 2019 to 29 March 2020.

As per Fig. 5.14, the surge in reporting was observable from the seventh week, when deployment took place in Polonnaruwa, showing the interest of commercial farmers in using the artifact to report crop disorder incidents. The farmers reported a total of 74 crop disorder incidents. The percentage of incidents reported by each district is compared in Fig. 5.15. Based on the comparison, the highest percentage (58%) of farmer reporting was recorded in Polonnaruwa, which accounted for 43 crop disorder incidents, followed by 19

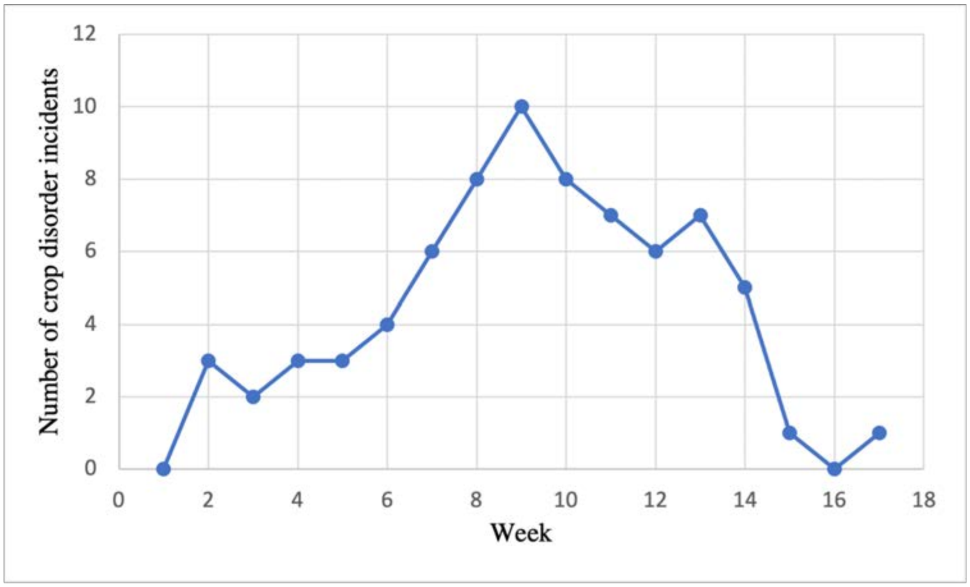


Figure 5.14 Number of reported crop disorder incidents by week

crop disorder incidents (26%) from Kurunegala and 12 incidents (16%) from Matara. Fewer incidents were reported in Kurunegala and Matara mainly because smaller areas of land were cultivated by the farmers in these locations, which makes them easier to manage than the larger areas in Polonnaruwa. In Polonnaruwa, stable access to the internet and farmers' interest in adapting the artifact was the major reasons that contributed to the higher number of reported incidents. Statistical evidence confirmed that there is an association between the participation of farmers in reporting crop disorder incidents against the districts ($X^2(2, n=116)=16.524, p <0.05$).

Similarly, of the farmers who reported the crop disorder incidents, 45% were aged under 40 years, as shown in Fig. 5.16. In Polonnaruwa, the majority of the reporting farmers were aged under 40. In Kurunegala, the majority were aged 40–50 years, while in Matara, 50% of the farmers were aged over 50 years. Statistical evidence also showed a significant association between age and the reporting of crop disorder incidents. This suggests that farmers aged under 40 (i.e., young farmers) were more interested in reporting crop disorder incidents than those in older age categories ($X^2(2, n=116)=7.607, p <0.05$).

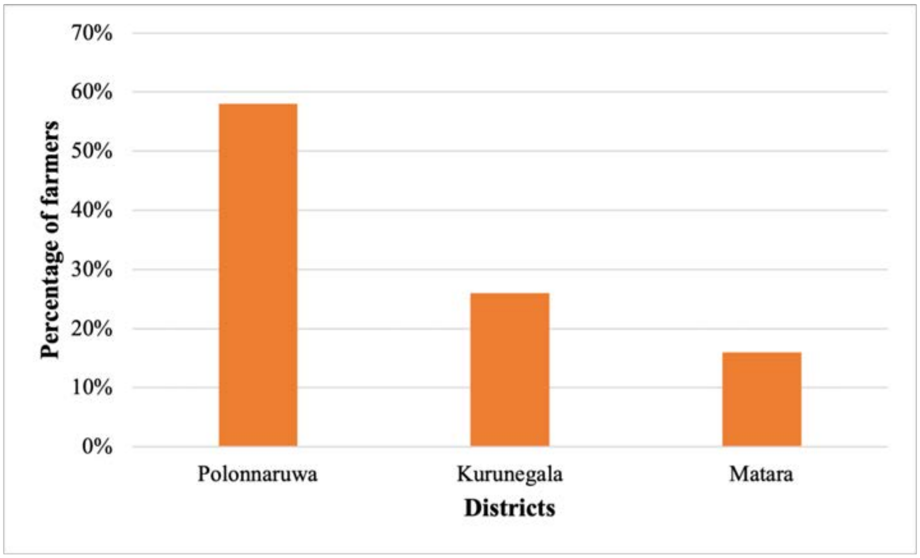


Figure 5.15 Percentage of farmers who have reported crop disorder incidents by districts

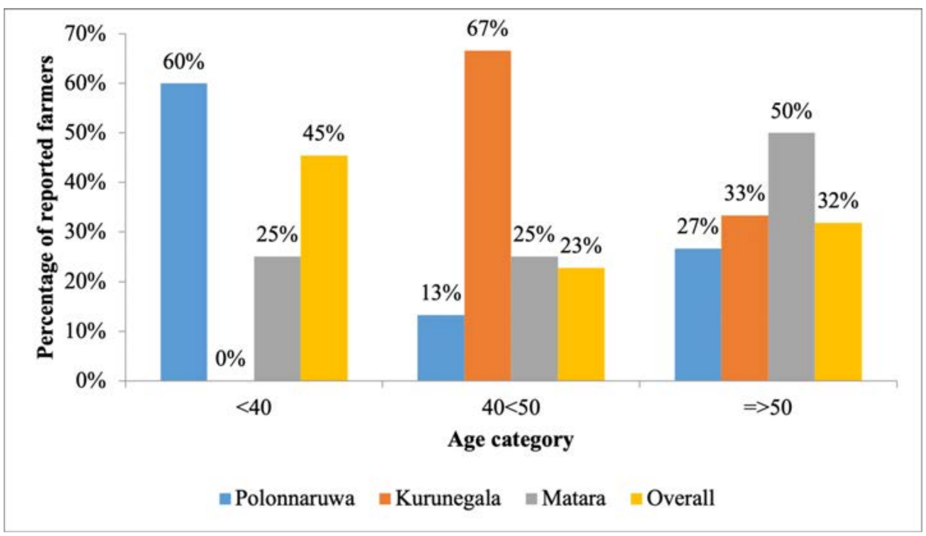


Figure 5.16 Percentage of farmers who have reported crop disorder incidents by age category

From a different perspective, providing farmers with information that assist them in making correct decisions is a crucial task. Therefore, the information presented through the artifact must be clear enough for them to make correct decisions. However, the effectiveness of the solution mainly depends on the extent to which farmers were able to select a matching identifier when comparing it with their actual field observations. Accordingly, the subject experts examined the attached images of each crop disorder incident independently to understand this measure. The responses from the experts were then compared with the output generated by the system based on the disorder identifiers chosen by the farmers. The pictorial depiction of this comparison is presented in Fig. 5.17.

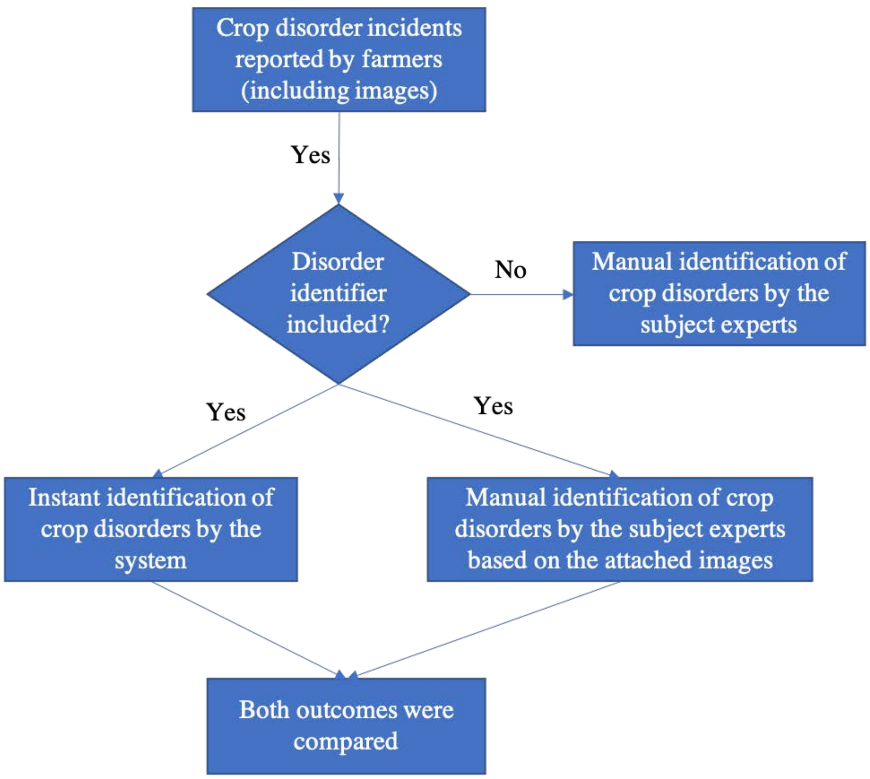


Figure 5.17 A comparison used to measure the ability of farmers in selecting correct disorder identifier

The primary objective of this experiment was to assess the effectiveness of the new artifact in replacing the subject experts' abilities. The results indicate that 48 of the total 74 reported incidents were reported, with the relevant disorder identifications being chosen by the farmers. Other incidents were not accompanied by any relevant disorder identifiers being selected. The major factor that limits farmers from selecting the suitable disorder identifier was the difficulties in selecting a matching identifier when comparing it with their actual field observations. Therefore, the correctness of farmer selection was assessed only by considering the remaining 48 incidents. Among the 48 reported incidents, 14 involved farmers selecting incorrect disorder identifiers, resulting in mismatches when compared to the choices made by experts. Accordingly, the farmers' ability to select the right disorder identifiers has been calculated at 70.8% and these were associated with disorder identifiers which provide a clear and consistent representation of the presence of relevant crop disorders. Consequently, the significance of the ratio implies that the majority of crop disorders can be identified instantly in the presence of the corresponding identifiers. Also, farmers are able to match their field observations with the provided list of crop disorder identifiers and were able to select one that fit their observations the best.

Aside from the above experiment, it is critical to assess whether farmers can utilize the resulting artifact to achieve specific goals in their context effectively, efficiently, and with satisfaction. Failure to meet farmers' expectations when using such mobile artifacts can lead to a lack of trust, the abandonment of tasks, and a decrease in satisfaction. According to a recent study, poor usability is the primary reason why many ICT applications are rejected by their users (Bilgihan, 2016). The usability of the artifact presents a number of challenges that need to be addressed when assessing it. These challenges include conducting a controlled experiment under field conditions with many environmental variables involved (such as climate, soil conditions, and management methods) and the lack of comparable artifacts which makes comparison difficult. Therefore, the ADR team has decided to conduct a usability evaluation based on farmers' perceptions of their past and current experiences with the artifact before and after it was created. As per ISO 25010 standards, the usability of a software system can be rated in many ways; however, factors such as appropriateness, recognizability, learnability, operability, aesthetics of the user interface, and access to them were found to be the most relevant ones for this study (iso25000.com, 2022). Following the ISO standards described above and the guidelines outlined in section 3.4.3, a post-evaluation study was designed with impact indicators defined as illustrated in Table 5.9.

Impact indicators
A. Obtaining the required responses in a timely manner and assisting in prompt decision-making
B. Assistance provided in the selection of recommended agrochemicals, dosage level and application instructions
C. Applicability of the provided information in practice
D. Reduction in the number of agrochemical applications compared with previous seasons
E. Knowledge enhancement on IPM approaches
F. Reduction of crop yield losses due to reduced crop disorders and agrochemical usage
G. Increased yield quality due to reduced crop disorders and agrochemical usage
H. Reduction in the cost of agrochemicals
I. Increased profits as a result of reduced agrochemicals usage
J. Assistance provided in planning precautionary steps to prevent crops from crop disorders
K. Adaptation towards using artifact and willingness to share with others
L. Perception of the application in terms of user-friendliness
M. Overall perception—use of the artifact in managing crop disorder incidents

Table 5.9 Impact indicators used to assess the impact of the artifact

Getting the required responses in a timely manner and assisting in prompt decision-making (Indicator A)

Analysis of the responses collected from the farmers regarding indicator A is provided in Fig. 5.18. The results revealed that 88% of the farmers claimed that they received the required information, especially the control measures on time. The timely delivery of the required information also encouraged the farmers to take necessary action on time to minimize further crop damages and reduce the chances of being dependent on unreliable sources to obtain the required information. Further, farmers' opinions on manual identification of crop disorders through a series of interactions with subject experts revealed that the way of interaction used in the developed solution was very helpful, especially in obtaining responses from subject experts on time compared to the earlier situation. Moreover, 8% of the farmers neither agreed nor disagreed with the statement, and 4% disagreed. The main reason farmers disagreed with the statement was the internet connectivity issues identified in the study locations. To assist farmers in obtaining the necessary control measures, the artifact must be online. However, the limitations associated with internet connectivity prevent the system from sending the necessary information back to their mobile phones; therefore, farmers think the system has failed to respond quickly.

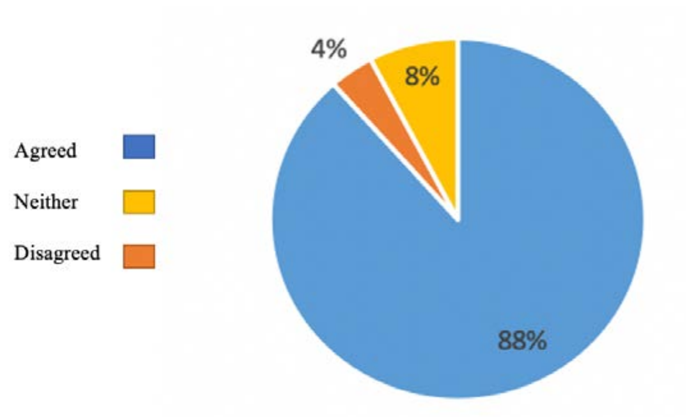


Figure 5.18 Farmers' opinions towards indicator A

Assistance provided in the selection of recommended agrochemicals, dosage level and application instructions (Indicator B)

Analysis of the responses collected from the farmers regarding indicator B is presented in Fig. 5.19. As discussed, crop disorder management remains a severe problem in Sri Lanka. This is widely influenced by frequent and overuse of agrochemicals, the application of mixed agrochemicals and not adopting recommended practices such as applying control measures at the onset of crop disorder incidents. The results obtained from the farmers revealed that 85% were satisfied with the information they received through the artifact in terms of recommended agrochemicals and the dosage level to be used, along with the appropriate application instructions.

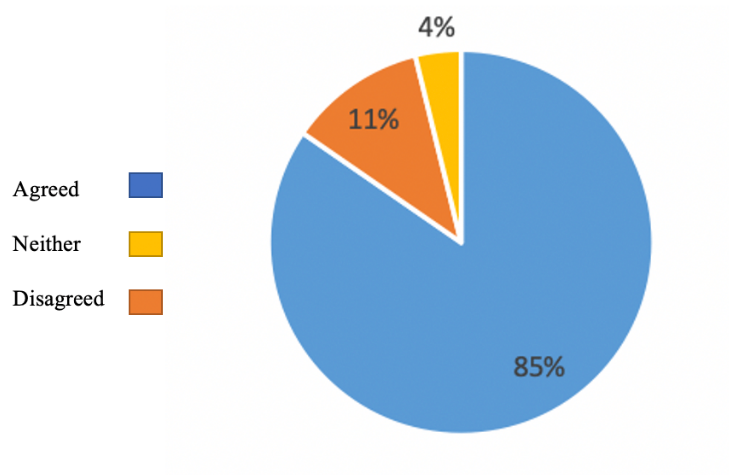


Figure 5.19 Farmers' opinions towards indicator B

Further, farmers realized the need to adhere to the recommended practices and, in return, reduce crop damages, increase their income and improve human and environmental safety. Moreover, 4% of the farmers neither agreed nor disagreed with the statement, and 11% disagreed. A discussion with the farmers showed that the reason farmers disagreed was that they were new to such interventions linked to crop disorder management; hence, it will take some time to adapt to such technologies and adhere to the instructions given through the solution.

Applicability of the provided information in practice (Indicator C)

It is critical for farmers to employ recommended agrochemicals and adhere to appropriate application instructions in practice. This means that the provided information should be easy to follow and should not impose any practical limitations on farmers. Fig. 5.20 provides an analysis of the responses regarding indicator C. The results revealed that 85% of the farmers claimed that they were able to adapt and employ the provided recommendations in practice without any difficulties. Moreover, 11% of the farmers neither agreed nor disagreed with the statement, and 4% disagreed. Some farmers disagreed because they still believe that the excess application of agrochemicals or the mixing of different agrochemicals will result in better outcomes and following the given recommended control measures would not work in practice and would not alone minimize the crop damages.

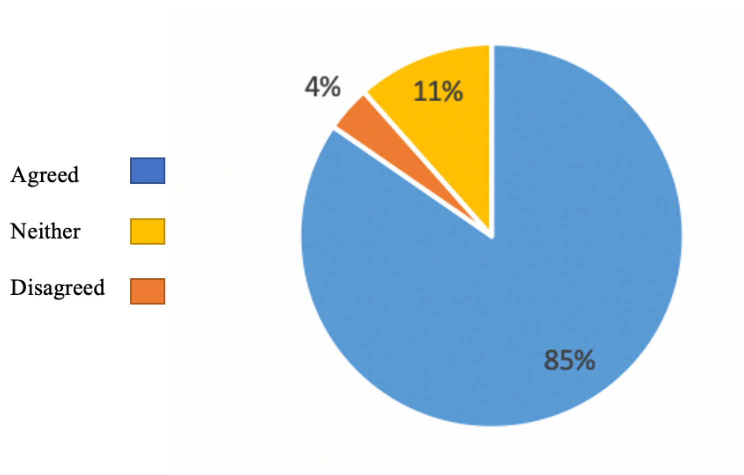


Figure 5.20 Farmers' opinions towards indicator C

Reduction in the number of agrochemical applications compared to previous seasons (Indicator D)

A reduction in the usage of agrochemicals is one of the core objectives to be achieved. After the trial period, farmers' opinions were collected in order to understand whether the artifact helped them adhere to recommended control strategies and, in turn, reduce their agrochemical usage compared with their past experience. Fig. 5.21 presents an analysis of the responses regarding indicator D. The results revealed that 77% of the farmers claimed they observed a significant change in the reduction of agrochemical usage compared with previous seasons. Further, the instructions provided through the application were significantly different from what farmers had been practising to date, and the artifact helped them realize the mistakes they had made. On the other hand, surprisingly, 23% of the farmers claimed they did not see any reduction in agrochemical usage. This was mainly because some farmers have applied agrochemicals even before any crop disorders occur due to the fear of potential crop losses.

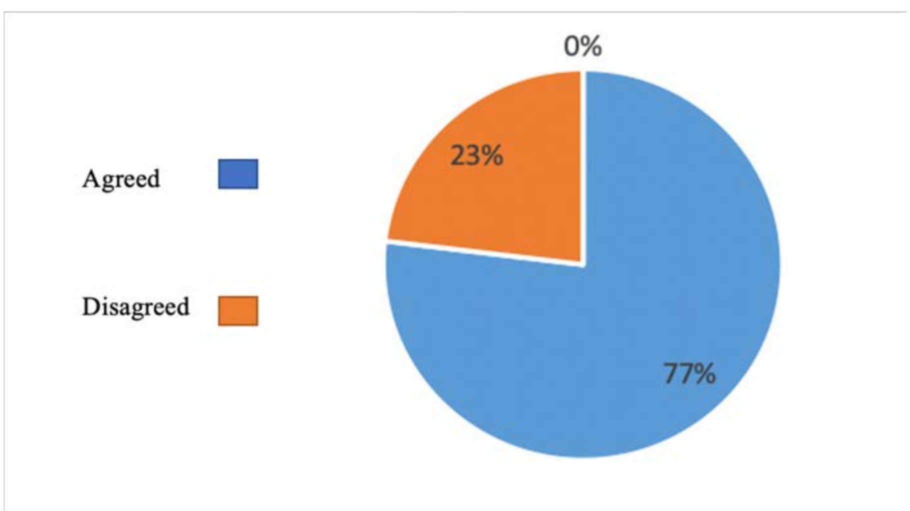


Figure 5.21 Farmers' opinions towards indicator D

Knowledge enhancement on IPM approaches (Indicator E)

It is highly recommended that farmers employ IPM-based techniques while managing crop disorder incidents. In the baseline study, it was found that although the farmers were aware of IPM-based approaches, they did not follow them in practice, and this was evident in the lack of information they had on how to incorporate the approaches. The farmers' opinions were obtained after using the artifact to assess whether they had access to the information, especially in regard to employing IPM-based recommended control measures. The results are presented in Fig. 5.22; surprisingly, all of the farmers claimed that the artifact had exposed them to various IPM-based approaches and enhanced their knowledge of how to employ them on the farm field. Further, the farmers stated that adhering to IPM-based approaches would help them prevent crop disorder incidents and reduce crop losses in the future.

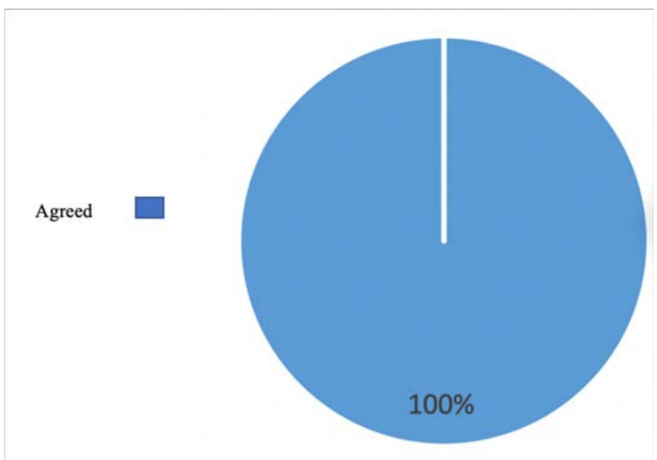


Figure 5.22 Farmers' opinions towards indicator E

Reduction of crop yield losses due to reduced crop disorders and agrochemical usage (Indicator F)

Agrochemicals are intended to be harmful. They have the power to control crop disorder incidents, but they are also harmful to crops and affect the overall yield produced. Reducing the use of agrochemicals during production boosts crop yields, reduces production costs and improves environmental and human health safety. Fig. 5.23 presents the farmers' opinions on the reduction of crop yield losses with the assistance provided through the artifact. The results consisted of mixed thoughts, with 38% of the farmers claiming that the overall yield losses had reduced compared with previous seasons. Further, they believed that the developed artifact helped them reduce the potential crop disorders in the current season compared with past seasons when they had significant crop losses and it also reduced their agrochemical usage. Moreover, 31% of the farmers neither agreed nor disagreed with the statement, and 31% disagreed. A discussion with the farmers showed that a reduction in yield losses depended on several other factors, including seed quality, climatic conditions, employing better farming practices and timely application of fertilizers, and they believed that a combination of these factors contributed to the reduction of yield loss.

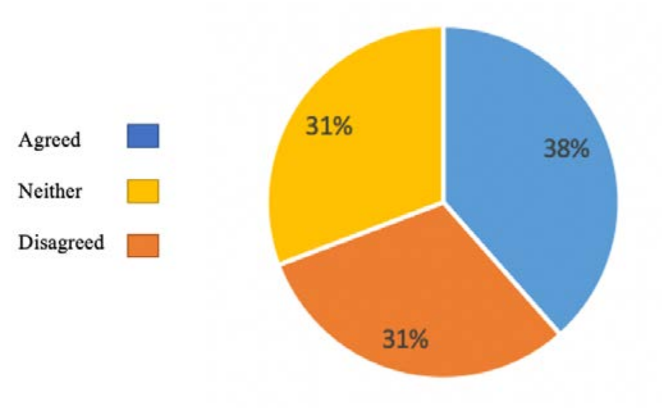


Figure 5.23 Farmers' opinions towards indicator F

Increased yield quality due to reduced crop disorders and agrochemical usage (Indicator G)

The application of agrochemicals directly onto the plants significantly affects the overall quality of the yield. As shown in Fig. 5.24, 35% of the farmers claimed the artifact had somewhat helped them reduce crop disorder incidents in the field and the overall agrochemical usage, which, in turn, helped them achieve a higher yield quality compared with previous seasons. More than 40% of the farmers stated that the yield quality depended on several other factors; hence, they were not convinced that the usage of the artifact was the only reason for the increased yield quality. Moreover, 23% of the farmers neither agreed nor disagreed with the statement made.

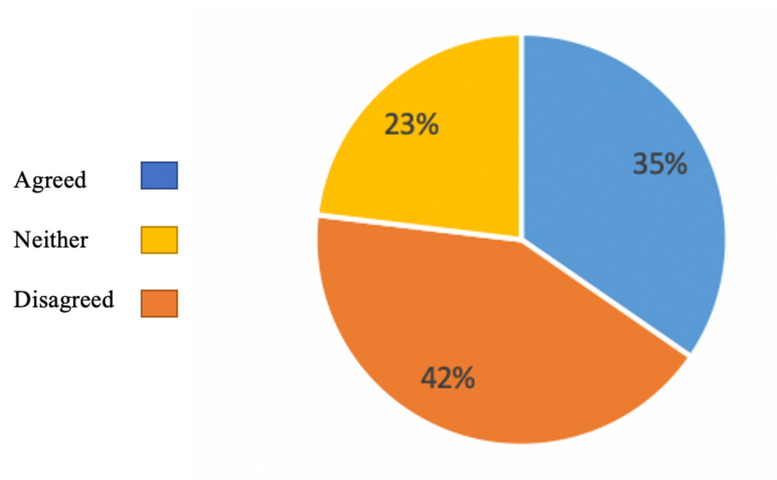


Figure 5.24 Farmers' opinions towards indicator G

Reduction in the expenses on agrochemicals (Indicator H)

Agriculture production costs, especially in relation to agrochemicals, have significantly increased due to a combination of reasons, including the excess application of agrochemicals, mixing different agrochemicals, and unnecessary application of agrochemicals before crop disorder incidents occur. After using the artifact , the farmers' opinions were analyzed to determine whether the overall expenses linked to agrochemicals were declined or not. The results, which are presented in Fig. 5.25, revealed that 69% of the farmers claimed that expenses related to agrochemicals had significantly decreased compared with the money they spent during the previous seasons. In contrast, 31% of the farmers stated that expenses related to agrochemicals remained the same, and they did not see any significant changes. A follow-up discussion with the farmers revealed that some farmers were still applying excess amounts of agrochemicals or were applying agrochemicals even before any crop disorder incidents occurred due to the fear of crop losses. The above reasons have pursued them to purchase agrochemicals as they practised to in the past.

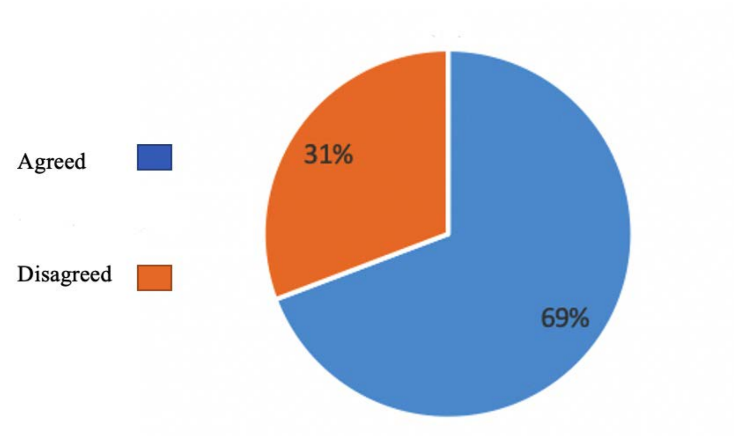


Figure 5.25 Farmers' opinions towards indicator H

Increased profits as a result of reduced agrochemicals usage (Indicator I)

The reduced use of agrochemicals results in a number of benefits, such as reduced expenses for agrochemicals, reduced overall production costs and increased profits. After the usage of the artifact , the farmers' opinions were analyzed to determine whether the overall profit had increased or not. The results are presented in Fig. 5.26. As shown, around 31% of the farmers claimed that their income had increased as a result of reduced expenses for agrochemicals and selling the harvest for a higher price due to the increased yield quality. However, 38% of the farmers were not satisfied with the statement. They still followed the traditional way of managing crop disorders instead of following the recommendations made available through the artifact . Further, the farmers stated that external factors, such as overproduction of the same crop varieties in the country, had significantly lowered the farm gate prices and affected their income, even though the cost associated with agrochemicals significantly declined. Moreover, 31% of the farmers neither agreed nor disagreed with the statement made.

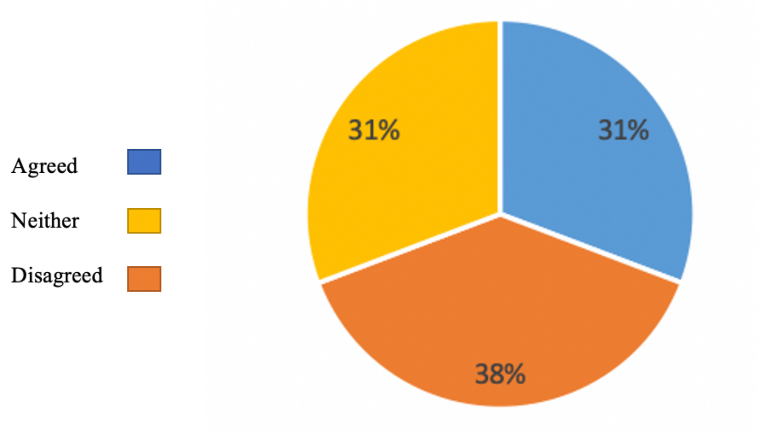


Figure 5.26 Farmers' opinions towards indicator I

Assistance provided in planning future activities to safeguard the crops from potential crop disorders (Indicator J)

Assisting farmers in implementing preventive control measures is vital to safeguard crops from potential crop disorders. This is achieved by employing effective IPM-based techniques. Fig. 5.27 presents an analysis of the responses collected from the farmers regarding indicator J. As shown, 92% of the farmers stated that the information they received through the artifact had helped them implement appropriate preventive control measures to safeguard crops from potential crop disorders. In contrast, 8% of the farmers disagreed with the statement and did not find that the information they received was helpful for safeguarding crops from potential crop disorders.

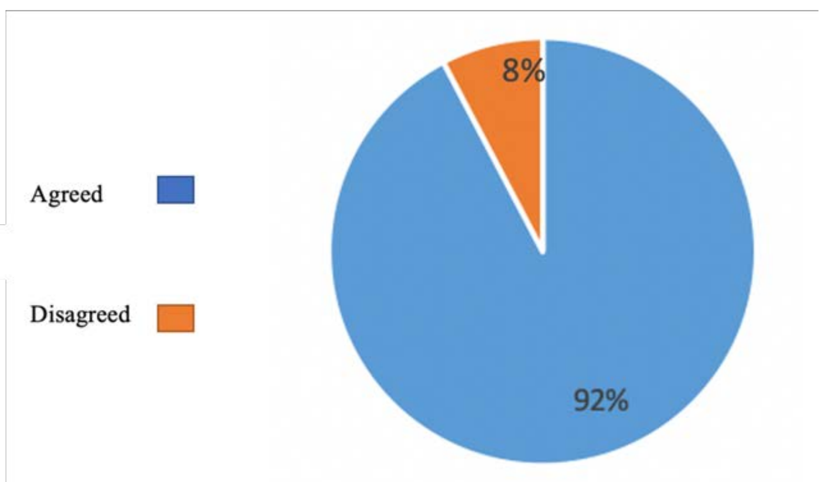


Figure 5.27 Farmers' opinions towards indicator J

The adaptation towards the artifact and willingness to share with others (Indicator K)

Having observed the positive outcomes and the benefits achieved through the artifact , especially in the crop disorder management process, the farmers pointed out that this artifact can be considered a potential tool that assists farmers in prompt decision-making to manage crop disorder incidents effectively. Moreover, having seen the strengths of the artifact , the farmers believed that this tool could attract many farmers at younger ages. Fig. 5.28 presents the analysis of the responses collected from the farmers regarding indicator K. As shown, 92% of the farmers were satisfied with the services provided through the artifact and had already started to use it in practice. Moreover, the farmers were keen to share their experience and the potential of the artifact with other farming communities to make them aware of such technologies. In contrast, 8% of the farmers neither agreed nor disagreed with the statement made.

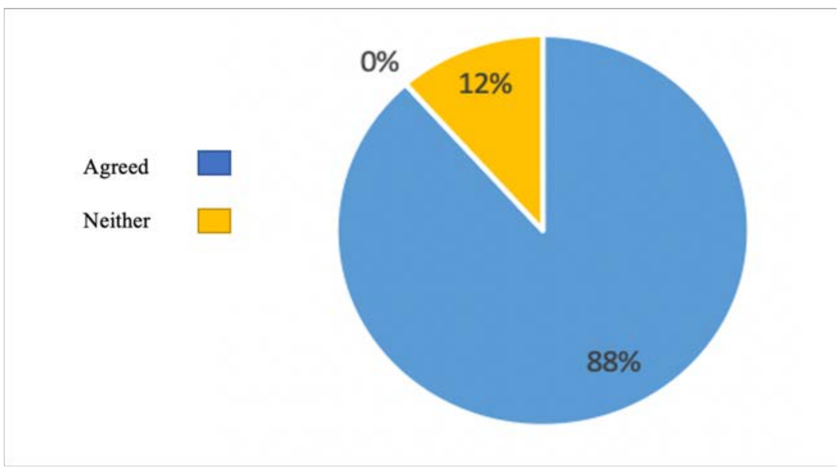


Figure 5.28 Farmers' opinions towards indicator K

Perception of the application in terms of user-friendliness (Indicator L)

During the post-deployment evaluation, the user-friendly aspect of the developed artifact was also measured. The results are presented in Fig. 5.29. As shown, 96% of the farmers claimed that they were satisfied with the current design of the developed artifact and could learn and use it easily without any challenges. Further, the farmers stated that the mobile screens of the artifact were not overly complex, and this helped them navigate through the mobile screens easier. In contrast, 4% of the farmers were neither satisfied nor unsatisfied with the statement made. On an additional note, a few farmers mentioned that some of the user interface (UI) elements used in the artifact were small in size, making it difficult to do selections on the mobile screens.

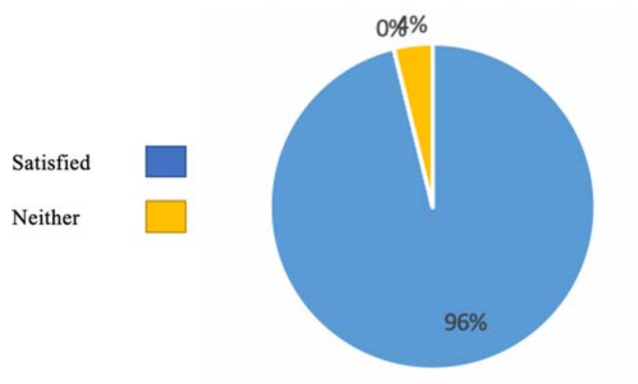


Figure 5.29 Farmers' opinions towards indicator L

Overall perception – use of the artifact in managing crop disorder incidents (Indicator M)

Finally, the farmers' perceptions of indicator M are presented in Fig. 5.30. As shown, 92% of the farmers were highly satisfied with the services rendered through the artifact , and they considered it as a helpful tool in managing crop disorder incidents. This is evident in the results above, which are presented based on the evaluation of various quality indicators.

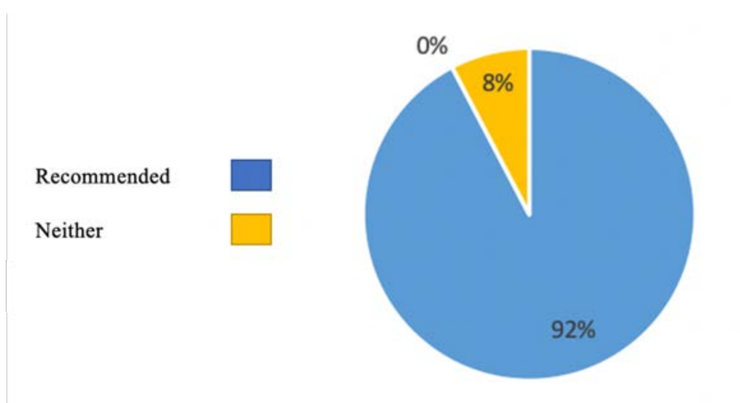


Figure 5.30 Farmers' opinions towards indicator M

Chapter Six

Reflection, Learning and Iteration 2

6.1 Reflection and Learning

In addition to the evaluation outcome of the developed artifact presented in Chapter 5, a summary of the reflection and learning during iteration one of the research was identified and presented below:

- Of the selected participants, most of the farmers in Polonnaruwa are large-scale commercial farmers, while those in Matara engage in paddy cultivation for self-consumption. In Kurunegala, the production orientation is a mixed target of both commercial and self-consumption. Farmers in Polonnaruwa showed more interest in the artifact, which indicates the vitality of farming-related technologies in commercial paddy farming.

- The sample farmers' involvement in community-based organizations indicates their greater capacity to influence the community regarding the artifact. This would result in horizontal diffusion among diverse groups of farmers.

- The sample paddy farmers in the study have shown a greater interest in participating since they have perceived the importance of the intervention, which enabled a constant engagement from them throughout the study period.

- Given Sri Lankan farmers' increased interest in using smartphones, a mobile artifact that incorporates the above features was chosen as a possible solution to assist farmers in managing crop disorder incidents. Furthermore, the responses collected from the participants through the baseline study further confirms the validity of the claim.

- Throughout this research study, the researcher and the members of the ADR team actively collaborated and participated in all research activities. This has resulted in the requirements being fully captured and implemented during iteration one of the research process, and no significant modifications were suggested to the developed mobile interfaces. This was mainly achieved due to the flexibility offered through the research methodology chosen in this study (ADR), which encourages active participation between the team members to solve a problem in an organizational setting.

- As a novel way compared to the existing attempts, the approach used in this research empowers farmers by providing the information in context for them to identify crop disorder incidents and, in turn, to obtain relevant control measures. Initially, a crop disorder search space that consists of mapping between different crop disorders and symptoms that provide unique search spaces specific to those crop disorders was created. Further, the information required to perform the search operation on the search space was obtained from farmers using a mobile artifact. As a result, the developed system can identify most crop disorders instantaneously, mitigating the factors that make crop disorder identification complicated. For the rest of the cases, the system provides a mechanism to identify crop disorders with the help of subject experts. Notably, this approach overcomes the limitations of existing attempts by using digital technology to empower farmers to identify crop disorder incidents.

- Despite the technical challenges farmers encountered during the deployment stage, farmers actively reported the field-level observations related to crop disorder incidents to the best of their ability to obtain relevant control measures. Their enthusiasm and motivation in using the mobile artifact to report such observations and satisfy their information needs reflect farmers' readiness to adapt to such solution.

- A total of 74 crop disorder incidents were reported by farmers, 48 of which had a corresponding disorder identifier selected by the farmers. A comparison between farmers' choices and experts' choices revealed that 34 of 48 incidents were reported with the correct disorder identifier, which led to an instant identification. This suggests a percentage of 70.8%. This allowed them to identify most of the crop disorders instantly and provide the necessary control measures in a timely manner. It reflects that crop disorders can be identified instantly given the corresponding disorder identifiers are being chosen by farmers.

- When the interaction between farmers and experts was examined for the remaining 26 incidents without the disorder identifier being chosen, it was found that the experts were interested in understanding farmers' responses to specific questions regarding climatic conditions, soil conditions, crop disorder symptoms distribution, and many others. By examining farmers' responses, the subject experts were able to exclude irrelevant crop disorders and narrow down their options. As a result of this observation, the ADR team was able to incorporate new properties the experts were seeking into the crop disorder search space identified from farmer-expert interactions. Identifying the additional symptoms will be a significant benefit to subject experts when it comes to identifying crop disorders by narrowing the search space and eliminating irrelevant possibilities.

- A post-evaluation study was conducted based on 13 impact indicators to understand the effectiveness, usability, and opinions toward the developed artifact. The evaluation of the results in section 5.5 showed that farmers were highly satisfied with the services rendered through the artifact and considered it a recommended tool for managing crop disorder incidents.

6.2 Limitations identified

With the resulted positive impacts, understanding the limitations of the developed artifact and incorporating further refinements are important tasks to be performed before rolling out the solution to a broader community. One of the important limitations identified was the incorrect selection of disorder identifiers by farmers from the given selection. This has resulted in the wrong identification of the crop disorder and the wrong control measures being suggested. The researchers found that, despite the fact that suitable options exist on the populated list of disorder identifiers, farmers chose incorrectly because of the difficulty selecting an appropriate identifier based on the actual field observations. Hence, to minimise the chances of farmers making an incorrect selection of the disorder identifiers, necessary refinements must be introduced to the existing design of the artifact.

In addition, as per the analysis of the user-friendly aspect of the artifact, as mentioned in section 5.5, farmers had difficulty operating the artifact on their mobiles due to the small elements and objects used on the mobile screens. This highlights that more thoughtful considerations are required to increase the usability aspects of the artifact. Further, stable internet access is also an important requirement to operate the artifact without any issues; however, the availability of different internet service providers and the poor internet signal strength in the study locations heavily affected the smoother operation of the artifact. Sometimes, due to a lack of internet connectivity, the artifact took a long time to retrieve the relevant information from the server, and the farmers had difficulty understanding what was happening. Hence, to minimize the time required for the artifact to be online, the artifact should partially function without internet access and use information that are transient in nature. Presently, the developed solution does not support this feature and the artifact requires continuous access to the internet.

Another limitation identified by us during the deployment of the artifact was farmers' smartphones running on different operating systems (e.g. iOS and Windows operating systems). From the development perspective, it is expensive to make the artifact support different operating systems because of the cost and effort required. Hence, the ADR team developed the artifact to support only Android users because most of the farmers were Android users. As a result, farmers who owned smartphones with other types of operating systems could not participate in the study. Moreover, due to the interactive features of the solution, the artifact requires a minimum of version 6 of the Android operating system. However, many of the sample farmers used earlier Android versions, resulting in an installation failure on their mobiles due to compatibility issues.

6.3 Iteration 2: Building, Intervention and Evaluation of the artifact

Based on the reflection, learning and limitations identified in iteration one of the research, the researcher decided to introduce some refinements to the developed artifact. Accordingly, a few of the major refinements that were considered during iteration two of the research is outlined below:

- **Changes to the design aspects of the artifact:** to present the relevant information to farmers in a better way to minimize selection errors that arose when farmers were interpreting the given information (difficulties associated with selecting a matching identifier when compared it with their actual field observations).

- **Changes to the crop disorder search space:** Based on the interactions captured between the farmers and subject experts in regard to crop disorder identification, enrich the structure of the crop disorder search space to include different types of information the subject experts are interested in.

Changes to the design aspects of the artifact

Presently, the information relevant to the disorder identifiers is presented in textual format in the developed solution. Hence, as a possible improvement, a refinement was made to the existing design of the artifact to include both text and images with an exact depiction of the disorder identifiers to assist farmers in selecting the correct choice. In general, providing a piece of information in a visual format has several advantages; visuals can convey more in-depth information than text, and the human brain can interpret visuals much faster compared with text (Bobek & Tversky, 2016). Notably, this approach contrasts with the existing approaches reported in the literature where farmers have to provide images of their field observations, and with the proposed approach, the farmer is shown with the list of possible field observations in the form of text and images. Thus, farmers will see both text and image representation of the disorder identifiers when compared with their actual field observations. This helps to reduce the chances of farmers making incorrect selections. To reflect this design change, the mobile screens of the artifact were also modified, as shown in Fig. 6.1.

Similar to the previous experiment, the revised version of the artifact (Version 2) was also intended to be introduced among the selected sample. However, as a result of travel restrictions to the study locations due to the COVID-19 pandemic, the ADR team had to find a new farmer group to assess Version 2 of the artifact. Accordingly, the team was able to find a farmer group within the allowable travel distance. This farmer group explored both Version 1 and Version 2 of the artifacts. The new experiment is designed as follows;

- Farmers were given both Version 1 and Version 2 of the artifacts to carry out the experiment.
- Twenty random images that depict different crop disorders were selected and the farmers were instructed to use Version 1 of the artifact as given in Screen 1 of Fig. 6.1 to make suitable choices of disorder identifiers for each of the given images. The same

experiment was repeated with Version 2 of the artifact as given in Screen 2 of Fig. 6.1.

- The responses of farmers using both Version 1 and Version 2 of the artifacts were recorded (see Table B.13), and the results of the experiment are presented in Table. 6.1.

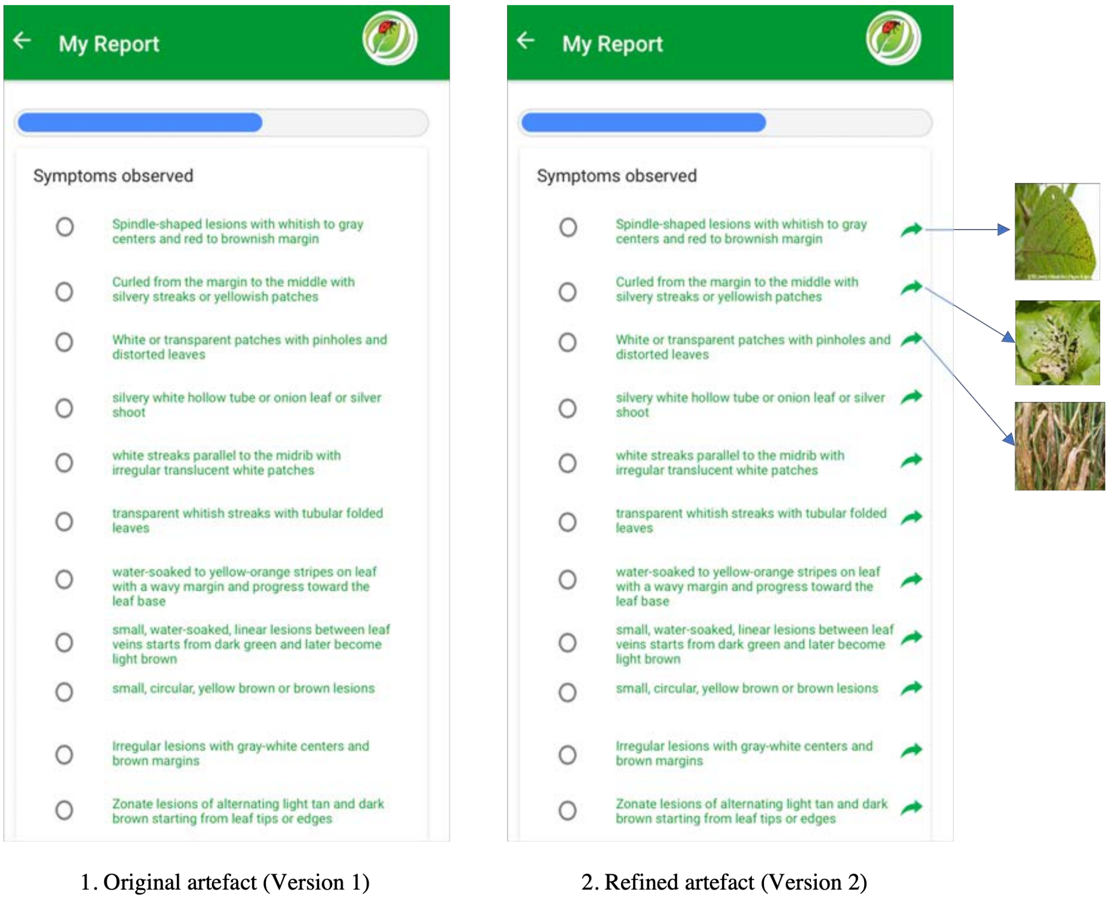


Figure 6.1 The comparison between the original (Version 1) and refined (Version 2) artifacts

As per the results, on average, the correct choices made by the farmers using Version 1 of the artifact was 11.5 out of 20 and using Version 2 of the artifact was 14.3 out of 20. Upon calculating the percentage of correct selection of disorder identifiers made by the farmers using both the versions of the artifacts, Version 1 registers 52.5%, and Version 2 registers 71.5%. Thus, presenting both images and textual representation of the disorder identifiers has resulted in farmers making correct selections than presenting information only in textual

Farmers	Version 1 (Number of correct selection of disorder identifiers - out of 20)	Version 2 (Number of correct selection of disorder identifiers - out of 20)
Farmer 1	15	17
Farmer 2	14	16
Farmer 3	10	15
Farmer 4	11	12
Farmer 5	13	17
Farmer 6	9	13
Farmer 7	13	17
Farmer 8	15	18
Farmer 9	9	13
Farmer 10	9	11
Farmer 11	15	17
Farmer 12	6	11
Farmer 13	12	13
Farmer 14	13	14
Farmer 15	13	15
Farmer 16	11	12
Farmer 17	9	13
Farmer 18	11	14
Farmer 19	10	13
Farmer 20	12	15
Average	**11.5**	**14.3**
Correctness	**57.5%**	**71.5%**

Table 6.1 Comparison of the results between Version 1 and Version 2 of the artifacts

format. However, before making any conclusions, the relevant statistical test has to be performed on the data to ensure that the difference is not randomly occurred by chance and is instead likely to be attributable to a specific reason. In order to perform a relevant statistical test, the data of both samples have to be normally distributed. The tests for normality can be performed through various techniques. Accordingly, the researcher employed the Anderson Darling test for normality check, and the outcome is presented in Fig. 6.2. Further, the hypotheses for the normality test were defined as follows:

Null hypothesis *(H_0)****:*** *data follow a normal distribution*

Alternative hypothesis *(H_1)****:*** *data do not follow a normal distribution*

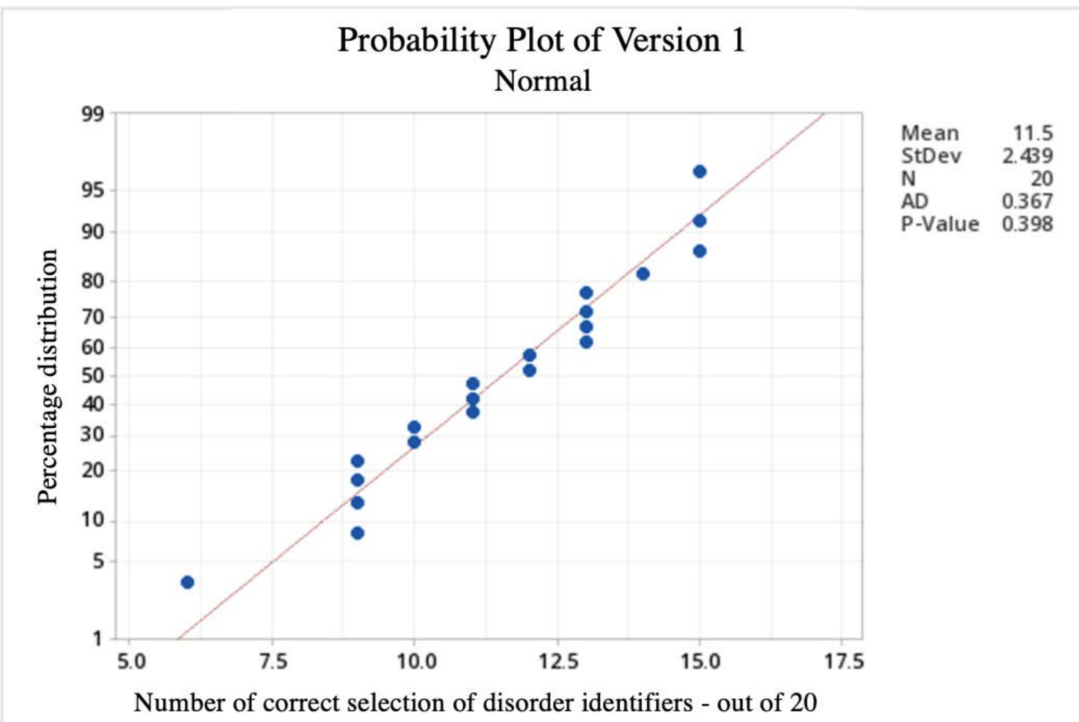


Figure 6.2 Outcome of the normality test for data obtained from the Version 1 of the artifact

In these two outcomes, the p-values of the data in both samples were 0.398 and 0.156,

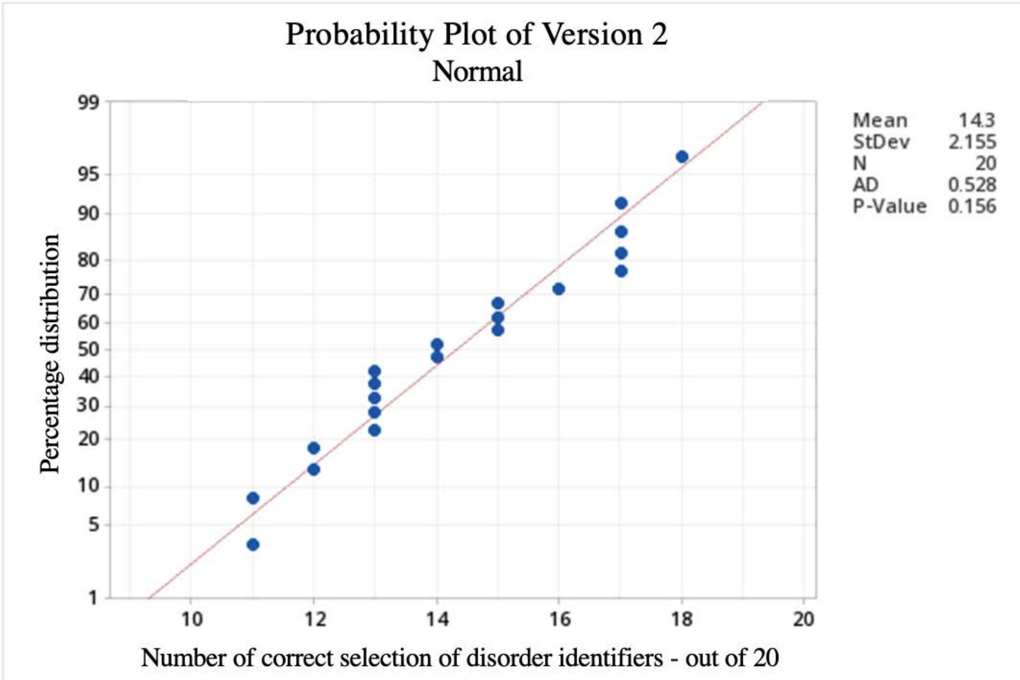


Figure 6.3 Outcome of the normality test for data obtained from the Version 2 of the artifact

which were greater than the significance level of 0.05. Hence, in both instances, the null hypothesis was not rejected. Moreover, in the given probability plots, the data in both samples formed an approximate straight line. Thus, it can be concluded that the data for both samples appeared to be a good fit for normal distribution. As a result of the normality test, to establish whether Version 2 of the artifact has reduced the selection errors that were apparent when farmers selected disorder identifiers over Version 1, a suitable statistical test needs to be selected. On an additional note, the nature of the evaluation conducted in iteration two of the research is that the responses were collected from the same farmer group under two different experiments (see Table. 6.1). Accordingly, the researcher selected the paired sample t-test (one-tail) to verify the claim made at the significance level of 0.05. The hypotheses were formulated as follows, and the outcome of the test is presented in Table. 6.2.

Null hypothesis **(H_0):** $\mu_{version_2} \leq \mu_{version_1}$

Alternative hypothesis **(H_1):** $\mu_{version_2} > \mu_{version_1}$

Based on the results, the p-value is calculated as $6.2502e^{-}9$, which is largely less than the significance level of 0.05. Thus, the null hypothesis can be rejected, and it is concluded that Version 2 of the artifact minimised the selection errors that arose compared with Version 1 of the artifact. This was achieved by presenting the relevant information in the form of both images and text. Notably, the nature of the evaluation conducted in iteration two of the research is different from that conducted in iteration one; therefore, the outcome of these evaluations cannot be compared.

	Version 2 of the artifact	Version 1 of the artifact
Mean	14.3	11.5
Variance	4.642105263	5.947368421
Observations	20	20
t Stat	9.472852778	
P(T<=t) one-tail	$6.2502e^{-}9$	
t Critical one-tail	1.729132812	

Table 6.2 The results of the paired sample t-Test (one-tail)

Changes to the crop disorder search space

Sometimes, when farmers could not find a suitable choice from the given list of disorder identifiers, they had to report their observations to the subject experts for identifying relevant crop disorders. This has resulted in subject experts communicating with farmers to determine the crop disorders present in the field based on the farmer responses. Further analysis of the interactions captured between farmers and subject experts revealed that the subject experts were interested to know from farmers about specific aspects related to growing conditions in the field. This is to narrow down the number of possible crop disorders in the crop disorder search space and discard irrelevant choices. As a possible extension to the existing structure of crop disorder search space, these specific aspects the subject experts were questioning can be regarded as additional classification classes. Accordingly, the researcher further revised these specific aspects with the help of the ADR team and included as "context classes" in the existing crop disorder search space. The revised version of the crop disorder search space is presented in Table 6.3 (see the red-coloured text), and the properties of the identified context classes are presented in Table 6.4.

Crop Disorder	Affected Part	Relevant Symptoms	Context Class A	Context Class B	.....
.....	.....	.....	.....	.....	
.....	.....	.....	.....	.....	
.....	.....	.....	.....	.....	
.....	.....	.....	.....	.....	
.....	.....	.....	.....	.....	
.....	.....	.....	.....	.....	

Table 6.3 Revised structure of the crop disorder search space

Context Classes	**Attributes**	**Elements**
Agrochemical spray record	N/A	Followed the recommendation on average for all the chemicals, less usage than the recommendation in average for all the chemicals, excess usage than the recommendation in average for all the chemicals, no use and mixed chemicals/misuse
Fertilizer application record	N/A	Excess or less MOP applied than recommended, excess or less UREA applied than recommended and excess or less TSP applied than recommended
Climatic conditions	Temperature, rainfall, wind, humidity	Combination of elements for each attributes
Soil appearance	N/A	Cracked, muddy, normal, wet
Symptom distribution in the field	N/A	Circular, random, rows, patch, uniform
Intensity of the problem	N/A	1-2 plants affected/m^2, 3-5 plants affected/m^2, and more than 6 plants affected/m^2

Table 6.4 Identified context classes, the associated attributes and elements

6.4 Reflection and Learning after Iteration 2

Farmers selecting incorrect disorder identifiers when reporting crop disorder incidents was an issue observed upon analysing the results collected during iteration one of the research. Analysis of the reasons revealed that the farmers had difficulties in interpreting the provided information through the artifact and selecting a matching identifier when compared it with their actual field observations. Possible changes were identified and made to the original artifact that was developed in iteration one of the research; as a result, the refined version of the artifact minimized the selection errors that arose when farmers select disorder identifiers compared to the original artifact. This was mainly because the relevant information was presented in the refined artifact as a visual and textual format rather than only in the textual format. The statistical tests also confirmed the validity of the hypothesis formulated regarding the results obtained from the refined artifact.

Analysis of interactions between farmers and subject experts during manual identification of crop disorders showed that the subject experts sought farmers' insights into specific aspects to determine the presence of relevant crop disorders. These aspects represented the broader context of the field's growing condition, such as climatic condition, soil condition, and historical agrochemical/fertilizer application related to the cultivation. Henceforth, in iteration two, relevant context classes were added as part of the disorder identifier in the crop disorder search space. This enriched information included in the crop disorder search space will help subject experts to eliminate irrelevant possibilities and identify the relevant crop disorders based on symptom observations and growing conditions present in the field.

Chapter Seven

Conclusion and future work

7.1 Summary of findings

We have developed a mobile application to correctly identify crop disorders from field observations and, in turn, assist farmers in managing those using recommended control measures while minimizing agrochemical usage. As a novel way compared to the existing attempts, our approach empowers farmers by providing the information in context for them to identify crop disorder incidents and, in turn, to obtain relevant control measures. A detailed finding of our approach is outlined in the upcoming sections. Notably, the following objectives were also achieved as part of this research to meet the overall aim formulated in Chapter 1.

- A mobile artifact was developed to obtain symptom-related observations from farmers and instantly identify crop disorders.
- Through the developed artifact, farmers were able to access recommended control measures to control crop disorders effectively and on time while minimizing agrochemical usage.
- The impact of the solution was assessed from farmer responses in terms of effectiveness, and the usability aspects.

A summary of findings related to the challenges of the crop disorder identification process and limitations of the existing approaches is also given in this section. Crop disorder identification from field observations is a complicated process that carries various challenges. These challenges can be briefly stated as the distinct appearance of symptoms based on the growth stage of the crop, affected part of the crop and development stage of the crop disorder, difficulties in identifying the correct crop disorder from a large number of possibilities, common symptoms manifested by different crop disorders.

Attempts have been reported in the literature to address these challenges associated with crop disorder identification; however, the existing approaches only provide limited support in the overall crop disorder management process and are workable only in a more controlled environment with several limitations. Notably, these approaches use images that depict the field observations as the primary input to carry out the crop disorder identification process through extensive application of machine learning and image processing techniques. Ideally, the images should be captured under the same conditions as those used to train such systems. However, the identification of crop disorders become obsolesced when these images do not depict the actual conditions in the field. For example, some factors may affect the quality of the images sent by farmers, such as angles, zoom level, light conditions, scales, and content configurations, thereby making such systems error-prone to perform meaningful identification.

From an application perspective, these approaches only focused on identifying a specific crop disorder or a small subset of crop disorders instead of all possible disorders associated with a crop, which in practice is too limiting. Likewise, from farmers' perspectives, farmers are the ones who sight such observations in the field at the first instance; hence, the involvement of farmers in correctly identifying crop disorders is an important aspect. However, in the reported approaches, this aspect has been completely disregarded, and this may extensively affect the correctness of such solutions.

Empirical findings

In order to achieve the aim, the main research question was formulated, and it was further investigated through two sub-research questions. The findings obtained while investigating the two sub-research questions are detailed below:

RQ1: How can the field-level observations relevant to crop disorders be effectively captured in practice?

This sub research question was formulated to find an effective approach to capture field-level observations observed by farmers to determine the relevant crop disorder. Farmers play a major role in the crop disorder identification process as they are the ones who observe the field observations at the first instance. Given the many uncertainties involved in obtaining symptom-related field observations as images, in this research, the researcher utilized the participation of farmers in a completely different way. Our approach empowers farmers by providing the information in context for them to identify crop disorders.

Initially, a causal analysis was carried out to depict the underlying relationships amongst varied factors involved in the overall crop disorder identification process. This activity helped the researcher understand the information that must be captured to perform crop disorder identification. The outcome revealed that crop disorders could exhibit different symptoms, and reporting the correct symptoms present in the field is necessary for the reliable identification of crop disorders. With difficulties associated with identifying symptoms present in the field and having a way to capture them effectively, the researcher developed a generalized structure to group symptoms of similar crop disorders together. These groupings were defined as symptom classes. Accordingly, the symptom classes and the relevant symptoms within each symptom class were identified for paddy with the help of subject experts in the ADR team. This has set the basis for the researcher to provide relevant information in context for farmers and, in turn, to obtain field-level observations.

RQ2: How can the crop disorder incidents be identified based on the field-level observations being captured?

This sub research question was formulated to determine the correct crop disorders based on the field-level observations captured from farmers. First, mapping was created between different crop disorders and relevant symptoms from the identified symptom classes for paddy. The outcome after the mapping was generalized as a crop disorder search space specific to a crop. The resulted crop disorder search space consisted of various characteristics, as discussed in Chapter 5. Further, it was also identified that some symptom(s) from the relevant symptom class(es) of crop disorders in the crop disorder search space would provide a unique way of identifying those crop disorders. This feature instantly distinguished most crop disorders, which could drastically minimize the effort required to identify crop disorders from larger possibilities. The symptom(s) that provide a unique way of identifying a crop disorder was defined as *disorder identifier*. Accordingly, a list of disorder identifiers was presented to the farmers using a mobile application to obtain the presence of a suitable choice from the given list. To enable farmers to make the correct selection, the information about the disorder identifiers was provided in text and image format.

The developed system can identify most crop disorders instantaneously, mitigating the factors that make crop disorder identification complicated. This leaves only a few instances that will require the intervention of subject experts to identify crop disorders, and the developed system also serves this purpose. Finally, after identifying the relevant crop disorders, the system was able to send appropriate control measures to farmers consisting of cultural, physical, mechanical, and chemical remedies while ensuring the environmental and human health safety aspects. Notably, in the developed approach, the knowledge required to identify different crop disorders is appropriately structured in the crop disorder search space; hence, subject experts can use this as a guide when interacting with farmers as well.

As part of the research, a number of experiments were conducted to evaluate the effectiveness and usability of the solution. The results of the experiments have shown that disorder identifiers that provide a clear and consistent representation of the presence of relevant crop disorders can be utilized to identify the majority of crop disorders instantly. It has also been demonstrated that farmers are able to correlate their field observations with the provided list of crop disorder identifiers and select the one that most closely matches their observations. As a result, it was possible to provide farmers with advice with regard to the cause and control of crop diseases as early as possible. Meanwhile, some of the crop disorders that did not have matching disorder identifiers were handled by the subject experts in consultation with farmers. The perception of farmers towards the developed artifact reveals that farmers were highly satisfied with the support provided by the system. According to farmers, losses in terms of yield quality and quantity have decreased in comparison with previous seasons due to fewer crop disorders. Moreover, the application of agrochemicals and associated costs have been reduced significantly, which has resulted in increased revenue for them.

Furthermore, the subsequent recommendations provided through the solution overcome various limitations associated with managing crop disorder incidents. As identified in Chapter 4, these limitations include poor adoption of recommended cultural practices; poor diagnosis of crop disorder incidents; insufficient knowledge of crop disorder management; heavy dependence on agrochemicals; reliance on unreliable sources in crop disorder management and thus, the reliance on unreliable sources in crop disorder management; improper selection, and overuse and misuse of agrochemicals.

7.2 Formalization of learning

The research was structured and the artifact was developed and evaluated based on the guidelines provided by ADR methodology. The researcher has chosen the ADR methodology in this study based on the characteristics of the problem under investigation.

- In this thesis, the problem discussed mirrors the characteristics of wicked problems leading to sub-problems with varying challenges, resulting in iteratively evolving requirements. Finding a solution to such a problem therefore calls for the involvement of experts in the relevant areas. Additionally, the researcher must continue to interact with the identified subject experts in order to fully comprehend the problem and develop a possible solution.
- The adaptation of ICT advancements and empowerment of human communities have affected how people respond to problems. It provided them with the opportunity to actively participate in creating and sharing information in order to resolve a variety of problems. Therefore, designing IT artifacts and empowering users by enabling them to perform actions would be a possible method to improve the flow of information in any process. As well, with the use of appropriate digital technology, there is the potential to instantly communicate relevant information to end users. The development of a suitable digital technology can thus be used to address community-oriented problems.
- From the users' involved in this research point of view, there is a need to change the work traditions of how farmers manage crop disorder incidents. A suitable digital technology can be developed as a solution to the problem; however, the solution's success depends on, whether the end-users trust and accept the solution. To better understand how the solution works in users' context and how they operate the solution, the researcher has to communicate with them constantly to obtain their opinions and feedback to revise the solution concurrently. Furthermore, constant interaction is also required to provide relevant training, technical assistance and troubleshoot if end-users encounter any problems.

In accordance with this, the research domains involved in this study are agriculture and ICT. In this research, through the adoption of ADR, the researcher interacted with the subject matter experts iteratively, which led to a continuous evolution of the understanding of the requirements during the design and evaluation of the artifact. Furthermore, it was observed that there was a solid bond among the research team members that made it possible for messages to be communicated quickly, as well as for changes to be made concurrently to the artifact. Accordingly, a generalized meta-design of the process resulted from the learning gained through this research is presented in Fig. 7.1. The process consists of three layers: knowledge base, information processing, and presentation. The activities and the learning captured in each layer are outlined below.

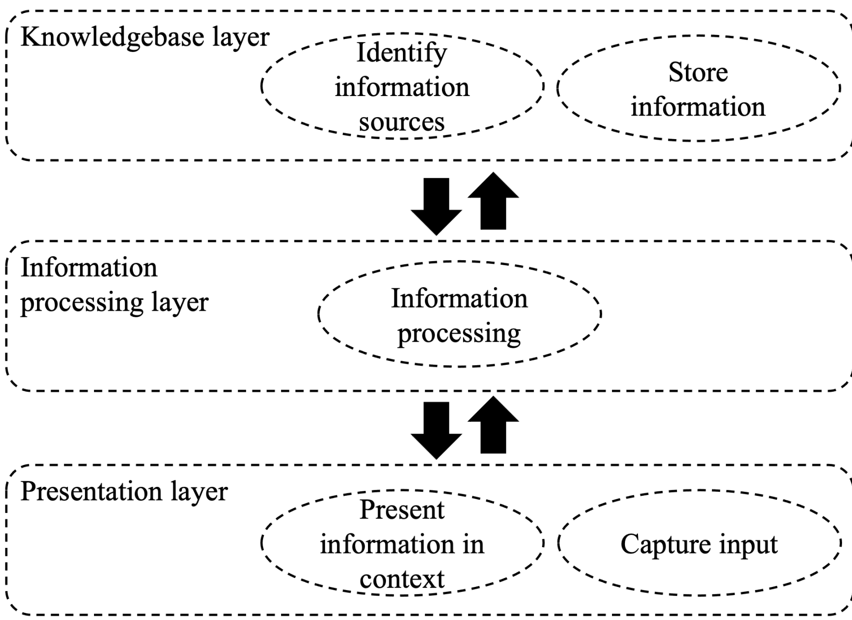


Figure 7.1 Meta-design of the process resulting from this research

Knowledge-base layer: This layer is dedicated to storing information about the problem that a researcher will address that evolved through a series of interactions with subject-matter experts. In general, each problem has its own challenges and constraints. In order to achieve a better understanding of the nature of the problem and to develop approaches to address it, subject experts from the specific domain must collaborate. This will help the researcher to understand their way of solving problems, fully capture the requirements, and identify sources to capture the required information. This action will result in an enriched knowledge base that consists of information about the problem being investigated and a complete set of design requirements that can be used to develop solutions with wider applicability. As an example from this research, the ADR team has developed a crop disorder search space that consists of information to identify crop disorders. The outcome of this research was also not limited to specific scenarios or conditions; instead, it can be largely extended and has broader applicability.

Information processing layer: User actions are enabled by this layer, which is dedicated to capturing and processing input and providing information. Several of the information systems proposed in the literature performed most of the information processing at this level, leaving users with few actions to perform. The system's capabilities were therefore limited, and the bulk of actions were performed at this layer. As an example specific to the problem discussed in this study, the researchers have developed many rigorous image processing and machine learning models to identify a single crop disorder through farmer provided images.

However, such approaches fail when these images do not depict the actual conditions in the field. Moreover, such solutions tend to identify only a specific type of crop disorder, and they cannot identify a broader group of problems due to practical limitations. These include the presence of partial symptoms in crops, the presence of common symptoms across different crop disorders, the appearance of symptoms in different parts of the plant, and variations in image capture conditions. Ideally, the images should be captured under the same conditions as those used to train such models. However, this can only be accomplished under more controlled conditions, similar to a laboratory, but not in practice. Furthermore, these systems also require a lot of processing power from the information processing aspect, which limits their accessibility for identifying the vast majority of crop disorders.

In contrast, our approach involves allowing the user to perform a bulk of actions instead of relying on the system that previously carried a lot of challenges. In this research, the information specifically identified for each crop disorder in the crop disorder search space was provided to farmers so they could make appropriate selections based on their field observations. The information captured from farmers is then used to identify crop disorders instantaneously. As a result of this shift in information processing pattern, the same process can now be performed on the user's side instead of requiring powerful systems or resources. Crucially, it will not limit the scope of the system and enable it to serve a wide range of purposes. The separation of actions also has the advantage of making it possible for this system to be applied to a wide range of crop disorders (broader applicability).

Presentation layer: This layer presents the information in context for the users and empowers them to perform actions. The performed actions will be captured as an input and will be processed at the information processing layer. In traditional systems, this layer was used only to display information for the users, and there was no information processing task associated. In this approach, the information presented through this layer requires the user to perform a bulk of actions. This will empower users to be part of the system and eliminate the limitations of the existing systems in terms of broader applicability and a huge processing load on the information processing layer. For example, in this research, the symptom(s) that can be used to uniquely identify a set of crop disorders were presented to farmers through this layer. In addition, relevant symptom selections from farmers based on their field observations were captured as user actions. The input from farmers was processed, and ultimately, instant crop disorder identification was performed.

As a result of this change in the way information is processed, a set of operations or actions may be performed quite differently than before. In addition, by enabling users to perform actions, this also empowers them to take part and engage with the system functions. As a result of this empowerment, communities are able to change themselves effectively and adapt to the changing environment. The proposed approach to information processing can also be adapted to a variety of other areas, including health care, transportation, education, and others. A number of recent studies have also confirmed that user-oriented systems have been generally accepted by the scientific community and can be used to alleviate many social problems in healthcare, transportation, and disaster management by mobilizing local communities (Fang et al., 2016; Filippi et al., 2013; Sakaki et al., 2010b). The problems that are encountered in the aforementioned domains are global challenges that require the domain knowledge and skills from multiple disciplines to overcome. According to a research study on global challenges, multidisciplinary research is a catalyst to tackling global challenges in science and technology (Ledford, 2015). Combining expertise and perspectives of various disciplines can pave the way for powerful insights and pragmatic answers to many pressing global challenges. To conclude the findings and leanings, a summary of the mappings between varied activities carried out by the ADR team in different stages of the research and the corresponding outcomes are presented in Table 7.1.

7.3 Barriers and required actions for wider adoption

From the researcher's perspective, this research was based on farmer empowerment to develop a solution to address the challenges of crop disorder identification and provide relevant information in context for farmers to make better decisions. Even though it is evident from the results that the developed approach has resulted in many positive impacts (as discussed in Chapter 5), it is unfortunate that some of the limitations act as barriers to wider adoption. On the basis of this research, the following limitations were identified and thus, established a need for actions for wider adoption.

- Millions of people have been affected by the recent COVID-19 pandemic, and the world's economies have been at a near standstill, with countries imposing restrictions to minimize the spread of the virus. As a result, going digital has become vital in many parts of the world. Henceforth, such interventions, especially in agriculture, can significantly add value. Despite the high prevalence of mobile telephones among the

Stages and Principles		artifact
Stage 1: Problem formulation		
Practice inspired research	The research was formulated with the focus on developing a system to effectively manage crop disorder incidents	Research gaps and possible areas that need improvements were identified and development of causal map
Theory ingrained artifact	Knowledge relevant to the nature of the problem domain and the related challenges were reviewed, and a baseline study was conducted to capture more requirements from the end-users.	
Stage 2: Building, Intervention and Evaluation		
Reciprocal shaping	The artifact was designed iteratively by addressing the challenges identified from the existing approaches	A conceptual solution was developed, followed by the development of the crop disorder search space and mobile artifact
Mutually influential roles	A collaborative effort was achieved from the ADR team, including subject experts related to ICT scientists, agriculture scientists, and socio-economists	
Authentic and concurrent evaluation	The artifact was evaluated within the ADR team and deployed among farmers to to trial the system, followed by a series of evaluations	
Stage 3: Reflection and Learning		
Guided emergence	The learning obtained after evaluating the artifact was incorporated to revise the artifact	A revised version of the artifact was developed
Stage 4: Formalization of Learning		
Generalised outcomes	A number of concepts that emerged as an outcome of this study that can be extended to address a class of problems	A shift in the information processing style through user-empowerment

Table 7.1 Summary of the ADR processes

population in Sri Lanka as a whole, poor signal strength remains a major obstacle to communicating the required knowledge to the farming community. Hence, changes must be made to improve the communications infrastructure of the country.

- The research findings indicated that there were also scenarios when the subject experts had to respond to the crop disorder incidents reported by the farmers via interacting with them. Thus, it is recommended that dedicated subject experts who can handle such cases must be assigned to the relevant ASCs, or suitable authorities can instruct the associated subject experts to execute this task as part of their role.
- In general, farmers are not technically empowered to take advantage of technology-based interventions. However, the outcome of this research suggests that they are keen to adapt and use such interventions in their farming practices. Therefore, relevant changes to the agricultural extension service, such as educating farmers and familiarizing them with such technologies, can be introduced to help farmers adapt to the interventions.
- Farmers' organizations can be assisted to empower their members to use such technologies to address farming-related issues at the community level.

7.4 Future work

Different types of extensions and experiments can be explored in the future to complement the work presented in this research. Future work could consist of an in-depth analysis of a number of factors that require development or further research, as outlined below:

- Although this research was focused on crop disorder identification in paddy, the outcome of this research can be extended to support crop disorder identification in other field crops in the agriculture and horticulture sectors that are with extensive application of agrochemicals.

- The derived crop disorder search space can be extended to include information about crop disorders that are in different development stages
- A real-time notification service can be developed to inform farmers about outbreaks in nearby areas and alert them to take precautionary control measures.
- Appropriate computing approaches can be used to automate interactions between farmers and subject experts concerning the specific context classes identified during iteration two of the research (e.g., decision trees, chat-bots).
- Usability aspects of the developed artifact can be further enhanced to provide end-users with a better user experience, especially when capturing field observations (e.g., voice clips).
- With the occurrence of crop disorder incidents captured through the system, input requirements specific to agrochemicals can be determined and communicated back to relevant authorities to adjust relevant incentives for farmers.
- The relevant information can also be shared with subject experts to improve the pest tolerance characteristics of the seeds.

In summary, the researcher found a method for empowering users, and this, in turn, has caused a change to the traditional way of processing information, with the aim of solving many similar societal problems.

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APPENDICES

Appendix A

Supportive information

Crop establishment method	Polonnaruwa		Kurunegala		Matara		Overall	
	Maha	Yala	Maha	Yala	Maha	Yala	Maha	Yala
Broadcasting	58	57	46	44	39	39	143 (80%)	140 (83%)
Transplanting	2	2	14	8	20	19	36 (20%)	29 (17%)

Table A.1 Crop establishment methods employed across districts and cultivation seasons

Duration	Variety Names
3 months	Bg 300, Bg 350, Bg 310, At 308, At 307
3.5 months	Bg 94-1, Bg 358, Bg 359, Bg 360 (Keeri Samba), Bg 366, Bg 373, At 362, Bw 363, Bw 364, Bw 367, Bw 372, Ld 368
4 months	Bg 403 (Mahasen), Ld 408
4.5 months	Bg 379-2, Bg 450

Table A.2 Varieties cultivated by sample paddy farmers

Recommendations	Polonnaruwa			Kurunegala		
	Awareness (n=60)	Adoption in Maha (n=60)	Adoption in Yala (n=60)	Awareness (n=60)	Adoption in Maha (n=60)	Adoption in Yala (n=56)
Standing water	100%	93%	92%	100%	100%	100%
Yaya cultivation	100%	95%	93%	100%	87%	88%
Plough depth	98%	83%	85%	100%	88%	86%
Second ploughing	100%	58%	50%	97%	78%	77%
Seed germination test	95%	82%	80%	95%	72%	73%
Resistant varieties	97%	68%	68%	97%	75%	77%
Organic manure	98%	27%	30%	100%	80%	79%
Urea application	100%	52%	52%	100%	50%	50%
Seed rate	97%	35%	38%	97%	63%	64%
Seed treatment	90%	43%	32%	95%	55%	59%
Paddy husk charcoal	90%	8%	8%	80%	12%	9%
Spacing	5%	5%	5%	18%	10%	9%

Table A.3 Percentage distribution of farmers by awareness and adoption of recommended practices in paddy cultivation across Polonnaruwa and Kurunegala

Recommendations	Matara		
	Awareness (n=59)	Adoption in Maha (n=59)	Adoption in Yala (n=57)
Standing water	100%	95%	95%
Yaya cultivation	98%	88%	86%
Plough depth	98%	78%	77%
Second ploughing	100%	85%	82%
Seed germination test	98%	63%	61%
Resistant varieties	93%	63%	63%
Organic manure	100%	78%	81%
Urea application	98%	68%	67%
Seed rate	93%	64%	63%
Seed treatment	92%	49%	49%
Paddy husk charcoal	81%	7%	7%
Spacing	31%	31%	30%

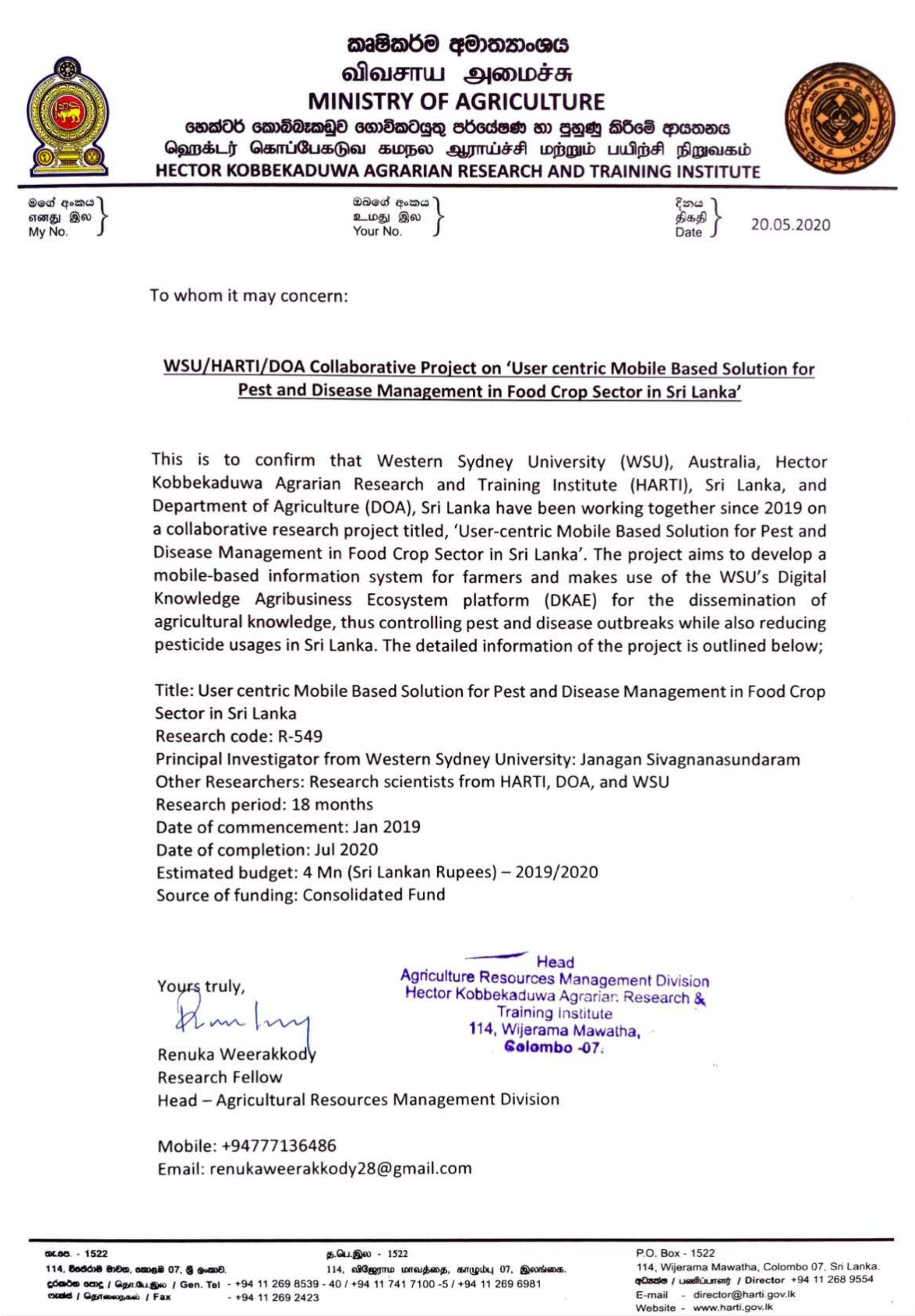
Table A.4 Percentage distribution of farmers by awareness and adoption of recommended practices in paddy cultivation across Matara

Appendix B

Official documents

Name	**Role**
Janagan Sivagnanasundaram	Researcher, WSU, Australia
Prof. Athula Ginige	Supervisor, WSU, Australia
Ms. Rifana Buhary	Coordinator/Research Officer, HARTI, Sri Lanka
Ms. Renuka Weerakkody	Supervisor/Research Officer, HARTI, Sri Lanka
Dr. Jeevani Goonathilake	Co-supervisor, University of Colombo, Sri Lanka
Ms. G.D.S.N. Chandrasena	Pathologist, Rice Research and Development Institute, DOA, Sri Lanka
Ms. K.R.D. Gunapala	Entomologist, Rice Research and Development Institute, DOA, Sri Lanka
Ms. Thushara Dharmawardhana	Research Officer, HARTI, Sri Lanka
Mr. Amal Dissanayake	Research Officer, HARTI, Sri Lanka
Mr. Virajith Kuruppu	Research Officer, HARTI, Sri Lanka

Table B.1 ADR team



කෘෂිකර්ම අමාත්‍යාංශය
விவசாய அமைச்சு
MINISTRY OF AGRICULTURE
හෙක්ටර් කොබ්බෑකඩුව ගොවිකටයුතු පර්යේෂණ හා පුහුණු කිරීමේ ආයතනය
ஹெக்டர் கொப்பேகடுவ கமநல ஆராய்ச்சி மற்றும் பயிற்சி நிறுவகம்
HECTOR KOBBEKADUWA AGRARIAN RESEARCH AND TRAINING INSTITUTE

මගේ අංකය / எனது இல / My No. — ඔබගේ අංකය / உமது இல / Your No. — දිනය / திகதி / Date 20.05.2020

To whom it may concern:

WSU/HARTI/DOA Collaborative Project on 'User centric Mobile Based Solution for Pest and Disease Management in Food Crop Sector in Sri Lanka'

This is to confirm that Western Sydney University (WSU), Australia, Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI), Sri Lanka, and Department of Agriculture (DOA), Sri Lanka have been working together since 2019 on a collaborative research project titled, 'User-centric Mobile Based Solution for Pest and Disease Management in Food Crop Sector in Sri Lanka'. The project aims to develop a mobile-based information system for farmers and makes use of the WSU's Digital Knowledge Agribusiness Ecosystem platform (DKAE) for the dissemination of agricultural knowledge, thus controlling pest and disease outbreaks while also reducing pesticide usages in Sri Lanka. The detailed information of the project is outlined below;

Title: User centric Mobile Based Solution for Pest and Disease Management in Food Crop Sector in Sri Lanka
Research code: R-549
Principal Investigator from Western Sydney University: Janagan Sivagnanasundaram
Other Researchers: Research scientists from HARTI, DOA, and WSU
Research period: 18 months
Date of commencement: Jan 2019
Date of completion: Jul 2020
Estimated budget: 4 Mn (Sri Lankan Rupees) – 2019/2020
Source of funding: Consolidated Fund

Yours truly,

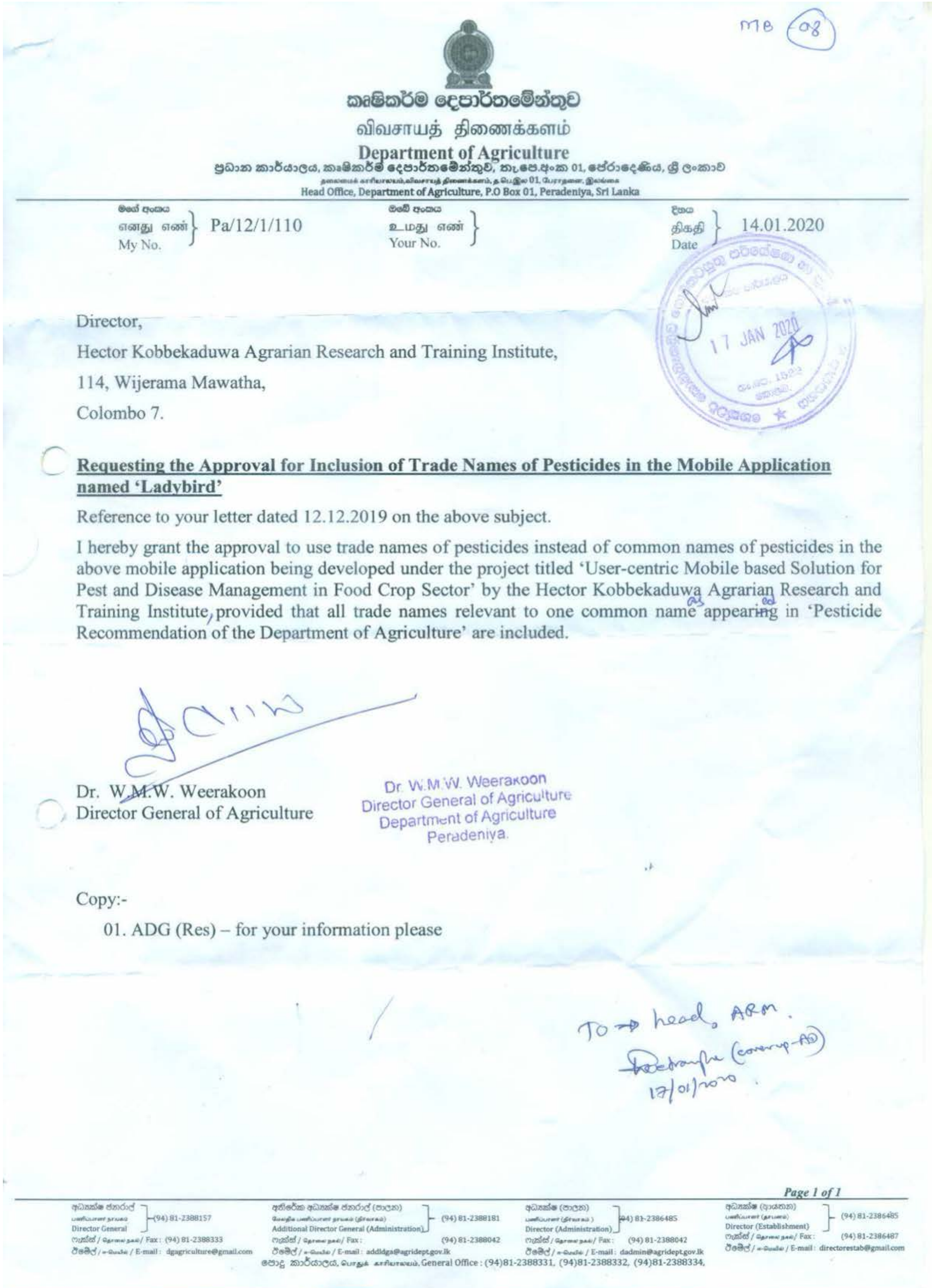
Head
Agriculture Resources Management Division
Hector Kobbekaduwa Agrarian Research & Training Institute
114, Wijerama Mawatha,
Colombo -07.

Renuka Weerakkody
Research Fellow
Head – Agricultural Resources Management Division

Mobile: +94777136486
Email: renukaweerakkody28@gmail.com

P.O. Box - 1522
114, Wijerama Mawatha, Colombo 07, Sri Lanka.
Gen. Tel - +94 11 269 8539 - 40 / +94 11 741 7100 -5 / +94 11 269 6981
Fax - +94 11 269 2423
Director +94 11 268 9554
E-mail - director@harti.gov.lk
Website - www.harti.gov.lk

Figure B.1 Background information about the collaborative project



කෘෂිකර්ම දෙපාර්තමේන්තුව
விவசாயத் திணைக்களம்
Department of Agriculture
ප්‍රධාන කාර්යාලය, කෘෂිකර්ම දෙපාර්තමේන්තුව, තැ.පෙ.අංක 01, පේරාදෙණිය, ශ්‍රී ලංකාව
Head Office, Department of Agriculture, P.O Box 01, Peradeniya, Sri Lanka

මගේ අංකය / எனது எண் / My No. Pa/12/1/110   ඔබේ අංකය / உமது எண் / Your No.   දිනය / திகதி / Date 14.01.2020

Director,
Hector Kobbekaduwa Agrarian Research and Training Institute,
114, Wijerama Mawatha,
Colombo 7.

Requesting the Approval for Inclusion of Trade Names of Pesticides in the Mobile Application named 'Ladybird'

Reference to your letter dated 12.12.2019 on the above subject.

I hereby grant the approval to use trade names of pesticides instead of common names of pesticides in the above mobile application being developed under the project titled 'User-centric Mobile based Solution for Pest and Disease Management in Food Crop Sector' by the Hector Kobbekaduwa Agrarian Research and Training Institute, provided that all trade names relevant to one common name appearing in 'Pesticide Recommendation of the Department of Agriculture' are included.

Dr. W.M.W. Weerakoon
Director General of Agriculture

Dr. W.M.W. Weerakoon
Director General of Agriculture
Department of Agriculture
Peradeniya.

Copy:-
01. ADG (Res) – for your information please

Page 1 of 1

Director General (94) 81-2388157, Fax: (94) 81-2388333, E-mail: dgagriculture@gmail.com
Additional Director General (Administration) (94) 81-2388181, Fax: (94) 81-2388042, E-mail: addldga@agridept.gov.lk
Director (Administration) (94) 81-2386485, Fax: (94) 81-2388042, E-mail: dadmin@agridept.gov.lk
Director (Establishment) (94) 81-2386485, Fax: (94) 81-2386487, E-mail: directorestab@gmail.com
General Office: (94)81-2388331, (94)81-2388332, (94)81-2388334,

Figure B.2 Authorisation received from relevant authority to include recommended control measures in the system

Serial No.	

User-centric Mobile Based Solution for Crop Disorder Management in Paddy Sector

Baseline Survey Questionnaire for Paddy Farmers

Hector Kobbekaduwa Agrarian Research and Training Institute

1. **General information**

1.1. Farmer's name :..
1.2. Mobile No. :..
1.3. Address :..
1.4. District :..
1.5. Agrarian Service Centre :..

2. **Information on Access to and Use of Mobile-based Tools in Agriculture**

2.1. Awareness and use of mobile calls for farming activities (Please mark "✓" or "×")

		a. Awareness	b. Use
2.1.1	DOA 1920 agri advisory service		
2.1.2	HARTI price 6666		
2.1.3	Dialog Govi Mithuru 616		
2.1.4	Other...................................		

2.2. Awareness and use of mobile Apps for farming activities (Please mark "✓" or "×")

		a. Awareness	b. Use
2.2.1	Crop forecast App		
2.2.2	SL – GAP App		
2.2.3	Hela Nutrition App		
2.2.4	Hela Bojun App		
2.2.5	Plant Treater App		
2.2.6	AIMS - Sinhala App		
2.2.7	Govi mithuru App		
2.2.8	Govipola App		
2.2.9	Govi Vedaduru App		
2.2.10	Krushi Adviser(1920) App		
2.2.11	Other.............................		

2.3. Awareness and use of mobile websites for farming activities (Please mark "✓" or "×")

		a. Awareness	b. Use
2.3.1	DOA website		
2.3.2	Croplook website		
2.3.3	WIKI goviya website		
2.3.4	Other.............................		

1

Figure B.3 Baseline survey form

2.4. Reasons for using mobile calls, Apps and websites for farming activities (Please mark "✓" or "×")

		a. Call	b. App	c. Website
2.4.1.	To determine cultivating crop, variety and date			
2.4.2.	To get information regarding pest and diseases			
2.4.3.	To get weather information			
2.4.4.	To get price and marketing data			
2.4.5.	To report problems about cultivating lands			
2.4.6.	Other…………………………			
2.4.7.				

2.5. Reasons for not using mobile calls, Apps and websites for farming activities (Please mark "✓" or "×")

		a. Call	b. App	c. Website
2.5.1.	Not aware			
2.5.2.	High cost			
2.5.3.	No network connection			
2.5.4.	No technical knowledge			
2.5.5.	No willingness			
2.5.6.	No reliability			
2.5.7.	Using computer/laptop			
2.5.8	Busy			
2.5.9	Not user friendly			
2.5.10.	Language difficulties			
2.5.11.	Other…………………………			
2.5.12.				
2.5.13.				

3. **Information on Telephone Usage by Members of Farm Family**

3.1. Total number of telephones used by the family members:....................................

3.1.1.	No. of fixed lines	
3.1.2.	No. of CDMA phones	
3.1.3	No. of smart mobile phones	
3.1.4	No of feature mobile phones	

2

Figure B.4 Baseline survey form continued..

3.2. Information related to mobile network

	3.2.1. Mobile network 1	3.2.2. Mobile network 2	3.2.3. Mobile network 3	3.2.4. Mobile network 4	3.2.5. Mobile network 5	3.2.6. Mobile network 6	3.2.7. Mobile network 7	3.2.8. Mobile network 8
a. Mobile network (Code 1)								
b. Reasons for choosing the network (Code 2)								
c. Type of phone (Code 3)								
d. Owner of the phone (Code 4)								
e. Purpose of use (Code 5)								
f. Internet use 1. Not use 2. Use if necessary 3. Always use								
g. Total monthly call and SMS expenditure for the network (Rs.)								
h. Total monthly internet expenditure for the network (Rs.)								
i. Total monthly expenditure for the network (Rs.)								

Code 1
1. Dialog
2. Mobitel
3. Hutch
4. Airtel
5. Etisalat
6. Sri Lanka Telecom
7. Lanka Bel
8. Other

Code 2
1. Wider network coverage
2. Low cost
3. Wide Service
4. Quality service
5. Generally used by majority of friends and family
6. Other

Code 3
1. Fixedline
2. CDMA
3. Smart mobile phone
4. Feature mobile phone

Code 4
1. Household head
2. Spouse
3. Son/daughter
4. Son or daughter in law
5. Grand children
6. Parents
7. Other relative

Code 5
1. Call
2. SMS
3. News or information
4. Education
5. Entertainment
6. Social media
7. Mobile banking
8. Online shopping
9. Reservation (e-channeling, travel booking, hotel booking)
10. Google map
11. Other

3

Figure B.5 Baseline survey form continued..

4. **Socio-economic information of farm family**

4.1. Farmer's age :.................................

4.2. The age at which mobile phone was first used :.................................

4.3. Marital status:........................ . 1. Married 2. Single 3. Widowed 4. Divorced/Separated

4.4. Ethnicity :........................... 1. Sinhala 2.Tamil 3.Muslim

4.5. The highest educational qualification (Code 6) :............................

4.5.1. Diploma qualification: 1. Diploma before GCE(O/L) 2. Diploma after GCE(O/L)

4.5.2. Name of the diploma course :...

4.6. Number of family members :....................................

4.7. Number of earning family members :.....................................

4.8. Primary occupation (Code 7) :......................................

4.9. Secondary occupation (Code 7) :......................................

Code 6
1. Not attended school
2. Grade 1 passed
3. Grade 2 passed
4. Grade 3 passed
5. Grade 4 passed
6. Grade 5 passed
7. Grade 6 passed
8. Grade 7 passed
9. Grade 8 passed
10. Grade 9 passed
11. Grade 10 passed
12. Until GCE (O/L)
13. GCE (O/L) passed
14. Until GCE (A/L)
15. GCE (A/L) passed
16. Graduate
17. Postgraduate diploma
18. Postgraduate degree

Code 7
1. Farming
2. Labour - farming
3. Labour - Non-farming
4. State sector employee
5. Private sector employee
6. Self-employment
7. Foreign employment
8. Skilled worker
9. Other

4.10. Monthly family expenditure (Rs.) :..................................

4.11. Monthly family income

	Description	Rs.
4.11.1	Monthly income from occupation	
4.11.2	Seasonal income	
4.11.3	Income from permanent crops	
4.11.4	Rental income (House/Vehicle)	
4.11.5	Samurdhi allowance	
4.11.6	Low income family allowance	
4.11.7	Senior citizens' allowance	
4.11.8	Other income	
	Total income (Rs.)	

4.12. Holding membership in community based organizations (Code 8) :..........................

4.13. Holding leadership position in community based organizations (Code 9) :...........................

Code 8
1. No
2. Farmers' Organizatio
3. Death Benevolence S
4. Sport Society
5. Youth Society
6. Women's Society
7.Rural Development Society
8. Samurdhi Movement
9. Shramadana Society
10. Other

Code 9
1. No
2. President
3. Vice-president
4. Secretary
5. Assis. Secretary
6. Treasurer
7. Assis. Treasurer
8. Committee member

4

Figure B.6 Baseline survey form continued..

5. **Information related to land (Information on land possess by the farm family with or without cultivation)**

a. Land plot	b. Type of land 1. Upland 2. Lowland	c. Extent	d. Land ownership (Code 10)	2018/19 Maha		2019 Yala		Permanent crop	
				e. Cultivated crop/land use	f. Extent	g. Cultivated crop/land use	h. Extent	i. Cultivated crop/land use	j. Extent
5.1.									
5.2.									
5.3.									
5.4.									
5.5.									
5.6.									

Code 10
1. Freeholding rights
2. Grants (Swarnabhoomi/Jayabhoomi)
3. Obtained for tenancy
4. Provided for tenancy
5. Obtained for lease
6. Provided for lease
7. Permit
8. Temple land
9. Katti maru
10. Thattu maru
11. Encroached
12. Obtained for mortgage
13. Provided for mortgage
14. Shared ownership

5

Figure B.7 Baseline survey form continued..

6. **Information related to paddy cultivation in a selected land plot**

6.1. Selected land plot No. :...

Information related to paddy cultivation	6.2. 2018/19 Maha	6.3. 2019 Yala
a. Extent cultivated		
b. Seed type used (Code 11)		
c. Seed variety used		
d. Field establishment method - 1. Broadcasting 2.Transplanting		
e. Nursery method if transplanted (Code 12)		
f. Source of water supply (Code 13)		
g. Quantity of Seed paddy used		
h. Source of seed paddy (Code 14)		
i. Use of harvest (Code 15)		
j. Quantity if sold		
k. Unit price if sold (Rs.)		

Code 11	Code 12	Code 13	Code 14	Code 15
1. 80-85 days 2. 3 months 3. 3.5 months 4. 4 months 5. 4.5 months 6. 5-6 months	1.Lowland nursery 2.Upland 3.Dapog 4.Machine transplanting 5.Parachute	1. Rain 2. Bore well 3. Tubewell 4. Agrowell 5. Minor irrigation 6. Major irrigation	1. Own 2. Registered farmers 3. Un-registered farmers 4. Agrarian Service Centre 5. Private companies 6. Department of Agriculture - sales centre 7. Other	1. Using as seed 2. Selling 3. Consuming 4. Other

7. **Yield loss in selected land plot**

	7.1. 2018/19 Maha	7.2. 2019 Yala
Post-harvest losses		
a. Expected yield		
b. Obtained yield		
c. Yield difference		
Reasons for yield difference (Specify the amount lost)		
d. Heavy rain		
e. Drought/water scarcity		
f. Wild-life damages		
g. Disease damage		
h. Pest damage		
i. Low quality seed paddy		
j. Issues in fertilizer use		
k. Soil infertility		
l. Weed growth		
m. Other....................................		

6

Figure B.8 Baseline survey form continued..

8. Main problems related to paddy cultivation

8.1 List in order and describe the major issues in the paddy cultivation focusing on the last two seasons

	8.1.1. 2018/19 Maha		8.1.2. 2019 Yala

8.2 Suggestions for overcoming problems faced in paddy cultivation

7

Figure B.9 Baseline survey form continued..

9. Application of recommended cultural practices for pest and disease management

Adopted recommended cultural methods to prevent and control pest and diseases using non-chemical methods. (Please mark "✓" or "×")

	9.1. Recommended practice	9.2. Awareness	Adoption		9.5. Reasons for non-adoption of recommendations
			9.3. 2018/19 Maha	9.4. 2019 Yala	
a.	All the farmers in '*Yaya*' begin cultivation activities simultaneously				
b.	Loosening the soil to the specified plough depth of 15-20 cm				
c.	Adding straw, green leaves and animal manure to the soil and plough the land followed by clearing of bunds before the first land preparation				
d.	Keeping standing water up to half the level of the bund after land preparation				
e.	Adding partially burnt paddy husk/straw to the field				
f.	Performing seed germination test				
g.	Cultivation of resistant varieties				
h.	Complying with recommended seed rates				
i.	Second ploughing after 10-14 days from the first land preparation by ploughing to the opposite direction				
j.	Treating seed paddy with fungicides				
k.	Complying with the recommended depth and spacing of planting (2-2.5cm depth and 15*15cm spacing)				
l.	Complying with the recommended rates of urea application				

Investigator's Name : .... Date: ....

Checked by : .... Date: ....

8

Figure B.10 Baseline survey form continued..

Serial No.	Paddy/KR/NW/
Name	
Date	

User-centric Mobile Based Solution for Crop Disorder Management in Paddy sector

Post Evaluation Questionnaire for Paddy Farmers – 2019/2020 Maha Season

Hector Kobbekaduwa Agrarian Research and Training Institute

1. <u>Observation and Reporting of Crop Disorders</u>

1.1 Did you observe crop disorders in the field?
1. Yes 2. No

1.2 Was the proposed mobile app useful for identifying them?
1. Yes 2. No

1.3 Did you use the mobile app to report those crop disorders?
1. Yes 2. No

1.4 Did the extension personnel respond to the submitted crop disorders reports in a timely manner?
1. Yes 2. No

1.5 Are you satisfied with the response given?
1. Yes 2. No

2. <u>Benefits obtained from proposed artefact</u>

2.1 The information provided by the mobile app has improved the knowledge on crop disorders and recommended management aspects.
1. Agreed 2. Disagreed 3. Neither

2.2 The overall yield outcome has increased in the 2019/2020 Maha season compared to 2018/2019 Maha season following the information provided by the proposed app.
1. Agreed 2. Disagreed 3. Neither

2.3 The overall profit has increased in the 2019/2020 Maha season compared to the 2018/2019 Maha season as a result of reduced agrochemical usage and following the information provided by the proposed app.

1. Agreed 2. Disagreed 3. Neither

1

Figure B.11 Post evaluation survey form

2.4 The overall quality of the harvest has increased in the 2019/2020 Maha season following the information provided by the proposed app.

1. Agreed 2. Disagreed 3. Neither

2.5 The proposed app is useful for selecting agrochemicals, employing recommended dosage level and application instructions off agrochemicals.

1. Agreed 2. Disagreed 3. Neither

2.6 The proposed app is useful in reducing the cost associated with agrochemicals.

1. Agreed 2. Disagreed 3. Neither

2.7 The frequency of using agrochemical has reduced in 2019/2020 Maha season following the information provided by the proposed app.

1. Agreed 2. Disagreed 3. Neither

3. Usability Aspects

3.1 Adaptation to the proposed intervention and willingness to share with others

1. Agreed 2. Disagreed 3. Neither

3.2 The simplicity of information provision, ease of use and ease of adoption

1. Agreed 2. Disagreed 3. Neither

3.3 Be able to exercise the instructions and the practices provided by the app

1. Agreed 2. Disagreed 3. Neither

3.4 Obtaining the required responses in a timely manner and assisting in prompt decision-making

1. Satisfied 2. Not satisfied 3. Neither

3.5 Assistance provided in planning future activities to prevent potential crop disorders

1. Agreed 2. Disagreed 3. Neither

3.6 Your assessment of the need for a such app for the farmer to manage crop disorders?

1. Recommended 2.Not recommended 3. Neither

4. Challenges faced

………………………………

5. Improvements.

………………………………

2

Figure B.12 Post evaluation survey form continued..

Serial No.	Paddy/KR/NW/
Farmer Name	
Date	

User-centric Mobile Based Solution for Crop Disorder Management in Paddy sector

Post Evaluation Questionnaire for Paddy Farmers (After Iteration 2)

Reports	Prototype after iteration 1 (choice no)	Prototype after iteration 2 (choice no)
Report 1		
Report 2		
Report 3		
Report 4		
Report 5		
Report 6		
Report 7		
Report 8		
Report 9		
Report 10		
Report 11		
Report 12		
Report 13		
Report 14		
Report 15		
Report 16		
Report 17		
Report 18		
Report 19		
Report 20		

1

Figure B.13 Post evaluation survey form used in iteration two of the research

Activity Number	Lifecycle Stage	Name of activity	Condition	Time	Time Units	Inputs	Description
1	Pre-Planting	Land preparation 1st		-21|-15	day	(Tractor|2|Hours/Ha) OR (Labour|3|People)	Loose the soil up to 15-20 cm depth using tractor, animals or human to burry previous debris and weeds. It helps to improve soil nutrients by mixing soil. After 1st land preparation bunds shoud be cleaned. Add organic materials such as glyricidia and paddy straw. Keep water in
2	Pre-Planting	Seed requirement	graintype:nadu	-21	day	(Paddy seed|100|Kg/Ha) OR (Paddy seed|75|Kg/Ha) OR (Paddy seed|200|Kg/Ha)	For wet seeding use 100kg/ha for dry seeding or 150-250kg/ha only specific conditions under kekulan and manawari cultivation for transplanting mentined on nursery bed preparation for parachute mentioned on nursery bed preparation
3	Pre-Planting	Seed requirement	graintype:samba	-21	day	(Paddy seed|100|Kg/Ha) OR (Paddy seed|75|Kg/Ha) OR (Paddy seed|200|Kg/Ha)	For wet seeding use 75-80 kg/ha for dry seeding or 150-250kg/ha only specific conditions under kekulan and manawari cultivation for transplanting mentined on nursery bed preparation for parachute mentioned on nursery bed preparation
4	Pre-Planting	Low land nursery	graintype:nadu	-21|-14	day	(Labour|70|People)	Better to use when you have enough water. Land or place should have good soil nutrient and enough sunlight. 1/10 of land from the cultivated extent is enough for nursery. Seed rate- 50kg/ha, 24 hours soaked, 48 hours incubated seed should be used. Plants are ready to plant after 14-21 days (according to age group).
5	Pre-Planting	Low land nursery	graintype:samba	-21|-14	day	(Labour|70|People)	Better to use when you have enough water. Land or place should have good soil nutrient and enough sunlight. 1/10 of land from the cultivated extent is enough for nursery. Seed rate- 40kg/ha, 24 hours soaked, 48 hours incubated seed should be used. Plants are ready to plant after 14-21 days (according to age group).
6	Pre-Planting	Low land nursery	graintype:nadu	-21|-14	day	(Labour|70|People)	Upland nursery can be used when water is inadequate to prepare a wet bed nursery. 5-10cm height and 90cm width beds are prepared. Space between rows should be 10-15 cm. Seed rate - 75kg/ha. Nursery should be covered with coconut leaves or any suitable material. Daily watering is needed.
7	Pre-Planting	Low land nursery	graintype:samba	-21|-14	day	(Labour|70|People)	Upland nursery can be used when water is inadequate to prepare a wet bed nursery. 5-10cm height and 90cm width beds are prepared. Space between rows should be 10-15 cm. Seed rate - 50kg/ha. Nursery should be covered with coconut leaves or any suitable material. Daily watering is needed.
8	Pre-Planting	Dapog nursery	graintype:nadu	-14|-12	day	(Labour|18|People)	1% of the total cultivatied area is enough for the nursery. Prepare the nursery 4-5 cm height. Put banana leaves or polythene on the nursery bed and 1 cm height compost or partialy burn paddy husk on that. 24 hours soaked and 24 hours incubated seeds are spread on the prepared bed as 2-3 seed layer. It should be tighten by hand or wodden frame daily until 3-4 days. Seed rate- 50kg/ha

Figure B.14 Knowledge captured from subject experts (package of farming practices)

Crop Name	Name of Pest/Disease	Symptoms	Cultural Control Methods	Chemical Control Methods
Paddy	Thrips	Both the larva and adult roll the leaf longitudinally to form a protective chamber. Existence of nymphs and adults in the rolled leaf tips. Damaged leaves have silvery streaks and translucent marks. Typical symptoms also include stunting and wilting or scorching. In severe infestations, seedlings may be died.	Early planting or Timely planting. Avoid staggered cultivation. In endemic areas and in late planted crops it is strongly advisable to do seed treatment. (please refer Chemical control methods)	(Ethiprole 10% SC| Curbix| Mix 10ml in 10L of water| Use 320-400ml of the prepared mixture to a Hectare) OR (Carbosulfan 20% SC| Marshal| Mix 20ml in 10L of water| Use 640-800ml of the prepared mixture to a Hectare) OR (Diazinon 50% EW/EC| Basudin,Director,Diamet,Diadin,Kafeer,Agstar,Disole| Mix 15ml in 10L of water| Use 480-600ml of the prepared mixture to a Hectare) OR (Imidacloprid 20% SL| Marit,Oasis,Armour,Baurs,Imidan,Sun Agro| Mix 5ml in 10L of water| Use 160-200ml of the prepared mixture to a Hectare) OR (Imidacloprid 70% WG| Admire, Provado| Mix 1.5g in 10L of water| Use 48-60g for a Hectare) OR (Thiacloprid 24% SC| Calipso| Mix 3ml in 10L of water| Use 96-120ml for a Hectare) OR (Fipronil 5% SC| Shutter, Regent,Zees,Baurs,CG,Arrears,Viper| Mix 5ml in 10L of water| Use 160-200ml for a Hectare) OR (Buprofezin 25% SC| Java| Mix 20ml in 10L of water| Use 640-800ml for a Hectare) OR (Pymetrozine 50% WG| Chess| Mix 4.4g in 10L of water| Use 140-175g for a Hectare)
Paddy	Rice gall midge	Development of 'onion shoot' like light colored galls in growing crops which is known as silver shoots. This is a pale cylindrical, hollow tube with a green tip replacing the normal culm . At severe infestations stunted plants, suppressed heading and enhanced tillering can be seen.	Use resistant varieties; Timely planting; Avoid staggered cultivation Avoiding excessive use of urea; Destruction of alternate hosts such as wild rifcce species & *Paspalum scrobiculatum*	(Fipronil 0.3% GR|ATL,Fipronil granules, Diligent 0.3 GR||Use 12g on wet mud or 1cm deep standing water after 1-3 weeks from sowing or 1-2 weeks from transplanting) OR (Diazinon 5% GR |Basudin, Diazinon||Use 22g on wet mud or 1cm deep standing water after 1-3 weeks from sowing or 1-2 weeks from transplanting)
paddy	Rice leaf folder	Longitudinal and transparent whitish streaks on damaged leaves; Tubular folded leaves; Leaf tips sometimes fastened to the basal part of leaf. Heavily infested fields appear scorched with many folded leaves	Early planting or Timely planting. Avoid staggered cultivation. Avoid unnecessary use of Urea. Appropriate plant density / reduce density Remove alternate weed hosts such as grassy weeds from the fields and border. Avoid ratooning Flood and plow field after harvesting if possible.	(Tebufenozide 20% SC|Mimic 20F|Mix 12ml in 10L of water|Use 384-480ml of the prepared mixture for a Hectare) OR (Chlorfluazuron 5% EC|Atabron 5 EC|Mix 8ml in 10L of water|Use 256-320ml of the prepared mixture for a Hectare) OR (Methoxyfenozide 24% SC|Runner|Mix 10ml in 10L of water|Use 320-400 of the prepared mixture for a Hectare) OR (Chromafenozide 5% SC|Podex|Mix 10ml in 10L of water|Use 320-400 of the prepared mixture for a Hectare) OR (Flubendiamide 24% WG|Belt|Mix 1.3g in 10L of water|Use 48g for a Hectare) OR (Chlorantraniliprole 20 + Thiamethoxam 20%WG|Vertako 40|Mix 2.5g in 10L of water|Use 100g for a Hectare) OR (Novaluron 10% EC|Rimon|Mix 10ml in 10L of water|Use 320-400ml of the prepared mixture for a Hectare)

Figure B.15 Knowledge captured from subject experts (crop disorders and recommendations)