IDENTIFICATION OF PACKAGE FOR GOOD AGRICULTURAL PRACTICE (GAP) FOR THE CULTIVATION OF HEAD CABBAGE FOR OPTIMUM YIELD, QUALITY AND FOOD SAFETY

(*Brassica oleracea* L. var. *capitata* L.)

SHALENDRA PRASAD

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE IN HORTICULTURE

GRADUATE SCHOOL

MAEJO UNIVERSITY

2012

APPROVAL SHEET

GRADUATE SCHOOL, MAEJO UNIVERSITY

THE DEGREE OF MASTER OF SCIENCE IN HORTICULTURE

Title

IDENTIFICATION OF PACKAGE FOR GOOD AGRICULTURAL PRACTICE (GAP) FOR THE CULTIVATION OF HEAD CABBAGE FOR OPTIMUM YIELD, QUALITY AND FOOD SAFETY

(*Brassica oleracea* L. var. *capitata* L.)

By

SHALENDRA PRASAD

APPROVED BY

Advisory Committee Chairperson ..... Nipon Jayamangkala
(Associate Professor Nipon Jayamangkala)
24 / 04 / 2012

Advisory Committee Member ..... Warunee Sirijornjaru
(Assistant Professor Dr. Warunee Sirijornjaru)
24 / 04 / 2012

Advisory Committee Member ..... J. Inthason
(Dr. Jiraporn Inthasan)
24 / 04 / 2012

Chairperson, Committee on Master of Science Program in Horticulture ..... Pompan Pooprompan
(Dr. Pompan Pooprompan)
24 / 04 / 2012

CERTIFIED BY
GRADUATE SCHOOL .....
(Assistant Professor Dr. Chamnian Yosraj)
25 / 04 / 2012

Title Identification of Package for Good Agricultural Practice (GAP) for the Cultivation of Head Cabbage for Optimum Yield, Quality and Food Safety (*Brassica oleracea* L. var. *capitata* L.)

Author Mr. Shalendra Prasad

Degree Master of Science in Horticulture

Advisory Committee Chairperson Associate Professor Nipon Jayamangkala

ABSTRACT

A field experiment consisting of three replications and 12 treatments were undertaken to determine the effects of different levels of nitrogen and plant spacing in a GAP production system using head cabbage at Maejo University, Thailand in 2010. Four levels of nitrogen; 0, 14, 16 and 18 kg per rai, with three different plant spacings (50 cm between rows x 30, 40 and 50 cm within rows) were laid out according to RCBD in a split plot arrangement.

In this study, yield per hectare for different levels of nitrogen was highly significant among plots when compared with the control (N=0). Nitrogen application level at 18 kg per rai produced highest yield of 62.8 tonnes per ha, while the control recorded the lowest yield of 42.4 tonnes per ha. However, plant spacing of 50 x 30 cm produced the highest yield of 63.6 tonnes per ha when compared to wider plant spacing of 50 x 50 cm, but head size was smaller. No interaction analysis was observed in the measured parameters but highest nitrogen level with wider plant spacing showed high levels of nitrate accumulation in cabbages.

In a separate experiment, a comparative study of four pest control systems (control, IPM, BT and Abamectin) were undertaken in a RCBD to assess its efficiency and test the Maximum Residual Level (MRL) of pesticide in the produce. Results showed no significant difference within the treated plots but they were however highly significant from the untreated plot (control). No pesticide residue was detected in the tested produce.

Keywords: head cabbage, nitrogen, plant spacing, head size, nitrate, pesticide residue

ACKNOWLEDGEMENT

First and foremost I would like to thank God almighty for showing me the right path and showering his blessings upon me during my studies at Maejo University.

This thesis would not have been possible without the regular guidance, encouragement and technical/scientific advice from the chairman of the research committee; Associate Professor Nipon Jayamangkala and the committee members; Assistant Professor Dr. Warunee Sirijornjaru and Dr. Jiraporn Inthasan. I am indebted for their enormous support.

I would like to show my gratitude to all the lecturers of the MSc. (Horticulture) programme; Dr. Pornpan Pooprompan, Asst. Prof. Dr. Chalermsri Nontaswatsri, Dr. Pranom Yangkhamman, Asst. Prof. Napadol Jarassamrit and Asst. Prof. Dr. Theeranuch Jaroenkit for imparting their knowlcdge and experience which made attending their classes interesting. Many thanks to the Faculty of Agricultural Production staff especially Miss Meena Prangrut, Mrs. Patcharaporn Chanta and Mrs Chumnian Srisaad and Mrs Diana Jantakad of the office of Vice President, international affairs for their regular support and making my stay in Thailand a memorable one.

I am grateful to Thailand International Cooperation Agency (TICA) and the Royal Thailand Governmcnt for awarding this scholarship to me. Especial thanks also to the Department of Agriculture, Ministry of Primary Industries, Fiji for believing in me and allowing me to undertake this programme.

I am grateful to my parents late Mr and Mrs Shiu Prasad of Qila, Tavcuni, Fiji for their sacrifices and dedication in educating me. My deepest gratitude to my beloved wife; Mrs Reshmi Lata Prasad and sons Sidhanth Sahil Prasad and Sushant Rahul Prasad for their continued support and encouragement to enable me to pursue further studies. I am totally indcbted to their sacrifice and sincerely thank them all.

It would not have been possible to achieve this milestone without the dedication, support, encouragement and sacrifice from my beloved wife. I therefore dedicate this work to her.

SHALENDRA PRASAD

April 2012

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND SYMBOLS USED

Abbreviation/symbol	Description
ACN	Acetonitrile
ADI	Acceptable Daily Intake
ANOVA	Analysis of variance
Assist.	Assistant
Assoc.	Associate
AVM	Avermectin B_1
AVRDC	Asian Vegatable Research and Development Centre
bw	Body Weight
฿	Baht
cm	Centimeter
cv.	Cultivar (variety)
CV	Coefficient of variation
DAT	Day after transplanting
DBM	Diamond Back Moth
DI	De-ionized water
DM	Dry matter
DMRT	Duncan's Multiple Range Test
EU	European Union
EPA	Environment Protection Agency
et al.	And other people
FAO	Food and Agriculture Organization
GAP	Good Agriculture Practices
GMO	Genetically Modified Organism (also Genetically Manipulated Organism)
Ha or ha	Heetare
HCL	Hydrogen Chloride
HPLC	High Performance Liquid Chromatography
IFOAM	International Federation of Organic Movements

IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
K	Potassium
Kg or kg	Kilogram
L or Lit.	Litre
Lab	Laboratory
LSD	Least significant difference
mg	Milligram
MJU	Maejo University (Chiang Mai, Thailand)
ml	Millilitre
mm	Millimetre
MRL	Maximum Residue Level
N	Nitrogen
NMIM	1-Methylimidazole
NO_2^-	Nitrite
NO_3^-	Nitrate
NS	Not significant
OM	Organic matter
P	Phosphorus
ppm	Parts per million
Prof.	Professor
RCBD	Randomized Complete Block Design
RfD	Reference Dose
SAS	Statistical Analysis System
TFAA	Trifluoroacetic Anhydride
TSS	Total soluble solid
USDA	United States Department of Agriculture
WHO	World Health Organization
µg	Micro gram
µL	Micro Litre

CHAPTER 1

INTRODUCTION

The production and marketing of high quality vegetables has become an important issue for the developing countries in order to maintain good market share both locally and abroad. The paradigm shift of consumers towards health and environmental concerns has demanded agricultural scientists to find solutions for the production of food crops that are produced in an environmentally friendly manner and are safe for human consumption. These challenges can be tackled in part through the Good Agricultural Practices (GAP) approach - a means to concretely contribute to environmental, economic and social sustainability of on-farm production resulting in safe and healthy food and non-food agricultural products (FAO, 2003). Product quality and food safety control have become basic trade conditions in, e.g., the European Union and also in the emerging economies of the South East Asia (Asandhi *et al.*, 2006).

Food safety is an important issue in Thailand. Good Agriculture Practices (GAP) for crops was implemented in Thailand in the year 2004 by the Department of Agriculture when the first GAP certification was granted at the beginning of the year even though the program was technically initiated in 1988 (Wannamolee, 2008). While most of the farmers of the Thailand Royal Project Foundation have been registered under GAP, there are still majority of non registered famers who still continue to produce fruits and vegetables under conventional methods using excessive amounts of fertilizers and pesticides. Chatupote and Panapitukkul reported in 2005 that the high rate of application of chemical fertilizers and pesticides in home gardens and commercial farms in the Rattaphum Catchment of Thailand that year led to the accumulation of nitrates in the top-soil, and contributed to the high potential for agrochemicals contamination in the groundwater in the area.

As such, the South Pacific region is also very vulnerable due to the fact that life is still highly dependent on the natural resources. One of the major problems faeed in the region is the exeessive use of mineral fertilizers and pesticides to produce horticultural crops. Apart from causing detrimental effects on the environment, the accumulation of toxic minerals and high pesticide residue levels pose a major threat to the safety of marine and human life and possible loss of the recently increasing export market opportunities. While it may not be possible for these countries to totally switch to organic crop production; it would however be beneficial to adapt GAP principles for

production of safe crops. Looking at the economies of scale for most of these small countries, any switch in the production system must be done without compromising the yield and quality of produce.

The current agricultural system promotes heavy reliance on agrochemicals, both synthetic fertilizers and pesticides, while neglecting to consider their negative effects on the human health and the environment. The long term use of high levels of agricultural inputs to boost crop yields have made it difficult to sustain the same rate of yield growth, however, production continues to increase but productivity rate per unit area has started to decline (Pathak and Ram, 2003). Moreover, increased intensity of land use has led to increasing input to maintain profit margins. Furthermore, the need to use large amounts of agrochemicals to control pests and weeds has raised environmental and human health concerns. Agrochemicals if not used responsibly pose health and environmental risks: they can pollute rivers and lakes through runoff and groundwater through leaching.

Agriculture mainly food crops, is expected to feed an increasing human population, forecast to reach 7,500 million by 2020, of whom 6,300 million will be in the developing countries. Although the rate of population growth is steadily decreasing, the increase in absolute numbers of people to be fed may be such that the carrying capacity of agricultural lands could soon be reached given current technology (FAO, 1999). To address this problem with an environmentally and economically sustainable way, production of quality food crops in a viable farming enterprise that are safe for consumption and contributes to sustainable livelihoods is mandatory. Thus utilizing the principles of GAP; where a holistic approach is taken to ensure sustainable food production is the answer for the future of agriculture.

Cabbage is one of the important vegetable crops cultivated for human consumption around the world. It is cultivated for its head, which consists of water (92.8%), protein (1.4 mg), calcium (55.0 mg), (0.8 mg), carbohydrates (6.0 g), carotene (0.3 mg), thiamine (0.06 mg), riboflavin (0.06 mg), niacin (0.3 mg), vitamin C (46 mg) and energy (92 kj); the leaves are eaten raw in salads or cooked (Adeniji *et al.*, 2010; Bediako-Asare *et al.*, 2010; Delannoy, 2001). The importance of head cabbage in tropical and subtropical regions has increased considerably in recent decades (Adeniji *et al.*, 2010).

Amongst the factors that affect yield and quality; population or plant density is one of the most important elements (Moniruzzaman, 2006; Pervez *et al.*, 2004). Cabbage yield usually varies with different plant densities. Suitable plant spacing can lead to optimum yield whereas too

high or too low plant spacing could result in relatively low yield and quality (Kobryn, 1987). Kratky *et al.* (1982), reported that wider plant spacing caused increased head size of lettuce, spear weight of broccoli and main head and auxiliary head size of cabbage. They further reported that head size of Chinese cabbage varied considerably when the plant spacing was irregular. Loiu, (1984) also reported that taro cv. Betelnut showed that the higher the plant density, the higher the plant and yield. However, size, weight and number of main corm produced on each plant were negatively correlated to the plant density. Optimum plant density is therefore an important parameter for the determination of productivity.

Nitrogen is the most abundant element in our atmosphere. It is a vital element as many classes of compounds essential to living systems are nitrogen-containing compounds. Nitrogen is a primary nutrient for all green plants, but it must be modified before it can be readily utilized by most living systems. It is one of the elements that are widely used to boost production of leafy vegetables around the world. Nitrate is a naturally occurring form of nitrogen and is an integral part of the nitrogen cycle in the environment (Santamaria, 2008; Michalski & Kurzyca, 2005). Due to the increased usage of nitrogen based fertilizers to produce vegetables and pasture, there may be an increased concentration of nitrates in the crops and the drinking water. The presence of nitrate in vegetables, as in water and generally in other foods, is a serious threat to man's health (Santamaria, 2008; Nantachit & Winijkul, 2007; Gaya & Alimi, 2006). Nitrates in the soil are a primary source of nitrogen which is essential for plant growth. Nitrate itself is relatively non-toxic but its metabolites, nitrite, is associated with methaemoglobinaemia. Nitrite might also react with amines to form carcinogenic nitrosamines in the stomach (EFSA, 2008). Nitrate predominately enters the human body exogenously from vegetables, water, and other foods, but is also formed to a limited extent endogenously (Lundberg *et al.,* 2004 and 2008). An estimated daily dose of nitrates consumed by man reaches 75-100 mg, of which 80-90% come from vegetables and 5-10% from water (Tannenbaum, 2000). The admissible concentration of nitrates and nitrites in drinking water in the majority of countries controlling these parameters is 50 mg per liter and 0.5 mg per liter, respectively (Michalski & Kurzyca, 2005; Nantachit & Winijkul, 2007). High nitrate content in vegetables are usually detected in marketed vegetables in the developing countries. Nantchit and Winijkul, (2007) reported that out of 33 vegetables tested in Chiangmai province in Thailand for nitrate, 18 kind or 54.5% had high nitrate content. Prasad and Chetty, (2007) also reported high nitrate contents (1,297

to 5,658 mg/kg) in their investigation on 4 leafy vegetables (Chinese cabbage, celery, lettuce & english cabbage) commonly consumed in Fiji.

Modern agriculture has evolved to the extent that consumers now expect to be able to buy an abundant supply of food, at a reasonable price, throughout the year. Farmers therefore often use pesticides to help them achieve this goal. However, the compounds used as pesticides for killing weeds, pests and moulds in crops are often harmful to people, wildlife and the environment. For this reason the sale and use of such compounds is very carefully controlled. The use of pesticides, including insecticides, fungicides, herbicides, rodenticides, etc., to protect crops from pests, allowed to significantly reduce the losses and to improve the yield of crops such as corn, maize, vegetables, potatoes, cotton (Carvalho, 2006) are used around the world for centuries.

The authorization of pesticide use is based upon Good Agricultural Practice. Yet it is recognizcd that, even use of GAP may still result in a erop with a detectable pesticide residue. Authorization for the use of a pesticide is therefore only approved if a risk assessment of residues levels in the crop shows the eonsumer risk is acceptable. Maximum Residue Levels (MRLs) for individual crop/pesticide combinations are therefore set on the basis of GAP. The Maximum (pesticide) Residue Levels allowable in foods are therefore extensively regulated and frequently redefined in both EU legislation and Codex (Lum, 2008).

Head cabbage was used as the test crop in the two different experiments to evaluate the effect of nitrogen and plant spacing and different pest eontrol methods on the yield, quality and food safety aspects of the test crop. In this research, quality indication of cabbage was indicated by the ineidence of pest and diseases, head firmness and head size while the food safety component was the nitrate and pesticide residual level in the leaves.

Objectives of the study

Following are the specific objectives of this study:

1. To find the effect of plant spacing on the growth, yield and quality of cabbage.
2. To find the effect of different levels of nitrogen on the yield and nitrate content of the cabbage.

3. To identify the best insect pest control method with minimum pesticide residual levels according to codex alimentarius guidelines.

4. To identify a package for cabbage cultivation according to Good Agricultural Practice (GAP) principles.

CHAPTER 2

LITERATURE REVIEW

Cabbage production

Cabbage (*Brassica oleraceae* var. *capitata*) is one of the most important leafy vegetables (Talekar, 2000) cultivated around the world. It originated in Northern Europe, the Baltic Sea coast (Monteiro and Luan, 1998) and the Mediterranean region (Vural *et al.*, 2000), where it has been grown for more than 3000 years and is adapted to cool moist conditions (Tindall, 1993; Thompson, 2002). The importance of head cabbage in tropical and subtropical regions has increased considerably in recent decades (Adeniji *et al.*, 2010). China is the largest producer of cabbages in the world followed by India.

Botany of Cabbage

Brassica oleracea L. includes all cabbage, collard and kale (Nonnecke, 1989) providing the greatest diversity of products used by man derived from a single genus (Dixon, 2007). This group has long been referred to collectively as "cole crops." Wild types of these crops have been found along the Atlantic Coast of Europe; cabbage, kale and collard are believed to have originated in Northern Europe (Monteiro and Luan, 1998). Early uses of these crops were for medicinal purposes (Nonnecke, 1989). The cole crops broccoli, brussels sprouts, cabbage, cauliflower, collards, kale, and kohlrabi belong to the same species (*Brassica oleracea* L.) in the Brassicaceae or mustard family. Kale most closely resembles the progenitor to this group of vegetables. Brassica is the most important genus, with about 40 species (Rubatzky and Yamaguchi, 1997) which are used as vegetables, oil, animal feed, ornamental and cover crops.

Cabbage and related cole crops belong to the species *Brassica oleracea* L. With exception of certain cabbages and some types of kale, this group has smooth, alternate leaves with lobed or wavy to highly dissected margins. Leaves may be thick and succulent, with or without a waxy bloom. The large yellow flowers are formed in elongated racemes (Nonnecke, 1989). Flowers possess four perpendicular petals that the medieval Europeans thought resembled a crucifix (thus the former family name Cruciferae). Flowers also have four sepals, a two-celled,

superior ovary with a single stigma and style, and six stamens, two of which have shorter filaments than the others. The fruit (seed pod) is a silique with a persistent, beaked style. The thin, 3-5 mm wide pods are 50-100 mm long and often dehisce when seed mature (Rubatzky and Yamaguchi, 1997). Seeds usually mature fifty to ninety days after fertilization. The species are insect cross-pollinated because self-pollination is prevented by a sporophytic self-incompatibility system. All naturally occurring *B. oleracea* L. are diploid with nine pairs of chromosomes. During domestication, different plant organs were emphasized. Kale and collards are the least modified from the ancestral form. Cabbage possesses a head composed of overlapping leaves formed on a shortened stem. Brussels sprouts form smaller heads in the leaf axils of the stem. The edible portion of kohlrabi is a shortened and swollen stem. Broccoli has been selected for an enlarged stem and inflorescence that is consumed when flowers are fully developed but have not yet opened. Like broccoli, the head of cauliflower is eaten. However, the head consists of a highly branched mass of undifferentiated shoot apices (curd) that only later may differentiate into floral primordia.

The cabbage is biennial plant which produces the head in its first year of growth. The head is best described as a single, large terminal bud comprised of tightly overlapping leaves attached to and enclosing most of the unbranched short stem (Rubatzky and Yamaguchi, 1997). As the leaves develop, the head will become solid and develop and head or heart (Dixon, 2007). It will form different head shapes such as pointed, conical or oblong, round or ball shaped or drumhead shape (Nonnecke, 1989). A cabbage plant is able to develop a strong tap root supported by a wide network of fibrous feeder roots which are located in the top 22 cm of the soil. Plant height commonly ranges from 40 and 60 cm (Rubatzky and Yamaguchi, 1997).

Cultivation of Cabbage

Climatic Requirements

Cabbage can be grown both in temperate and in (sub) tropical climates. Vegetative growth is optimum between 15 and 20 °C (Rubatzky and Yamaguchi, 1997) while temperatures more than 25 °C will adversely affect head density and shape. Some cultivars however are able to withstand considerable heat. Cabbages are not sensitive to photoperiods but prolonged exposure (four to six weeks) to cool temperatures in the juvenile stage will cut short vegetative

development and trigger flowering (Nonnecke, 1989) while warmer temperatures prolong the vegetative growth.

Soil Requirement

Cabbage grows well on medium and moderately heavy soil but it does best on a well- drained, loam soil that is well supplied with organie matter. Sandy loams are preferred for early crops. The best soil pH range from 6.0 to 7.5 (Nonnecke, 1989) Lower pH values will reduce growth and encourage clubroot disease therefore, soils having pH lower than 6.0 should be limed. Cabbages are fairly tolerant to soil salinity ((Rubatzky and Yamaguchi, 1997).

Nutrient Requirement

Cabbagc fertilizer requirements depend upon many factors, including variety, soil type and region, rainfall versus irrigation dependency and levels of organic matter in the soil (Nonnecke, 1989). A soil test is the most accurate guide to fertilizer requirements. Good management practices are essential if optimum fertilizer responses are to be realized in the production of cabbage. These practices include use of recommended varieties, selection of adapted soils, weed control, disease and insect control, good seedbed preparation, proper seeding methods, and timely harvest. Because of the influence of soil type, climatic conditions, and other cultural practices, crop responses from fertilizer may not always be accurately predicted. Soil test results, field experience, and knowledge of specific crop requirements help determine the nutrients needed and the rate of application. The fertilizer application for cabbage should insure adequate levels of all nutrients. Optimum fertilization is intended to produce top quality and yields in keeping with maximum returns.

Nitrogen (N) promotes vegetative growth. Like most leafy vegetables, cabbage needs a lot of nitrogen. Too little nitrogen reduces yields, delays maturity, and shortens storage life. Availability in excessive high quantities reduces yield and quality, increases susceptibility to pathogen invasion and leads to physiological disorders and delays in maturity (Dixon, 2007). The application of too much nitrogen (urea) however, may also result in a high percentage of nitrate in the leaves which is detrimental to the human health. Split application is necessary for efficient use of nitrogen. Generally total application of 90-110 kg N per hectare should be applied depending

on the N status of the soil. Broadcast half the quantity of N to the field before transplanting and apply remaining half 3 to 4 weeks after transplanting.

An excess of potassium (K) can cause the heads to burst and a deficiency of potash can result in necrosis at the margins of the leaves and a reduction in the keeping quality of the heads. Band applications of K should limit to 100 kg K_2O/ha, and broadcast remaining K and work into the soil prior to planting. Apply the following quantity of K:

If the soil test for K shows (ppm)	0 - 150	150 - 200	200 - 250	Over 250
Add this amount of K_2O (kg/ha)	225	81	44	None

High level of phosphorus (P) throughout the root zone is essential for rapid root development and for good utilization of water and other nutrients by the plants. Phosphorus fertilizer should be banded at the time of transplanting. Bands should be located 2-3 inches to the side of the plants and 3-4 inches deep.

If the soil test for P shows (ppm)	0 - 30	30 -50	>50
Add this amount of P_2O_5 (kg/ha)	225	81	44

Cabbage is very sensitive to micronutrient deficiencies. Deficiencies of trace elements have substantial effects on the yield, quality and storability (Dixon, 2007). Nonnecke (1989) and Dixon (2007) has reported that the cabbage is most sensitive to three micronutrients – boron, copper and zinc. Symptoms of boron deficiency may not be seen until the heads are cut. Severe affected plants develop rosetting and destruction of the terminal shoot (Nonnecke, 1989). Most cole crops develop cracked and corky stems, petioles and midribs. The stems of cabbage can be hollow and are sometimes discolored. Boronated fertilizer to be applied prior to planting at 20 kg/ha borax (sodium tetraborate) (Dixon, 2007) in deficient soils.

Production Methods

Cabbages can be successfully grown in greenhouses, under clear plastic films and open field cultivation depending on the seasonality of production. For better performance, cabbage seeds are normally grown in nurseries and latter transplanted to the field.

Seedling Preparation

The production of seedlings in cells, or individual pots, is the major method of raising transplants. Plants grown by this system are available from commercial nurseries or they can be raised on the farm. Transplants from this system suffer little transplanting shock and grow rapidly once transplanted into the field. Management of the young plants is easier than with bare-rooted seedlings.

Spacing and depth

Cabbage is generally transplanted however direct seeding is also practiced to a minimal extent. The seed requirement is 250-350 g/ha for transplanted seedlings that is sown in a depth of 0.5 to 1.0 cm. A plant spacing of 30 cm within rows and 50 cm between rows will give a plant population of 66,666 plants/ha. It is possible to control the size of heads by the spacing arrangements within and between rows (Nonnecke, 1989). The seedlings are ready for transplanting when they are 10 cm high or have 3-4 true leaves (Dixon, 2007).

Thinning

Thinning of seedlings sown in the plug container is necessary to achieve healthy seedlings. Leave only 1 healthy seedling (removing 1-2 unhealthy ones) during the first leaf stage.

Hardening

Seedlings should be gradually expose to strong sunlight daily and also reduction in water supply five days before transplanting to lesscn stress after transplanting.

Field Establishment

The field should be ploughed and harrowed until the soil is fine, leveled and free of weeds and plant debris. Bed is formed with a plow by opening furrows to a depth of 20 cm during the dry season or at least 30 cm during the wet season. The plants should be watered thoroughly at least 12 to 14 hours before transplanting to the field. Transplanting should preferably be done in the late afternoon or evening. Transplants usually have crooked stems; these should be planted up to the first leaves to ensure a sturdy plant that will not fall over when full sized. Irrigate frequently after transplanting during dry periods. Transplants are very sensitive to water stress.

Cabbage Growth Stages

Accurate cabbage growth stage descriptions are particularly useful in pest management since plant susceptibility to cabbage pests varies with the growth stage.

Table 1 Different stages of cabbage plant growth and development

	Plant Growth Stage	Description
Stage 1	Cotyledons (seed leaves)	No true leaves present.
Stage 2	Seedling	Up to 5 true leaves
Stage 3	6 to 8 true leaves	Ready for transplanting
Stage 4	9 to 12 true leaves	Base of stem still visible from above.
Stage 5	Precupping	Approximately 13 to 19 leaves. By the end of this stage, the base of the stem and the bases of all leaves are concealed when the plant is viewed from above. The innermost heart leaves are growing in an upright fashion and are visible without moving any of the surrounding leaves.
Stage 6	Cupping	Approximately 20 to 26 leaves. The innermost heart leaves, which are still

		growing in an upright fashion, are concealed by the larger, older leaves surrounding them. All visible leaves will later become the frame leaves (leaves not touching the mature head) of the mature plant.
Stage 7	Early head formation	Head diameter will be approximately 10 cm. The inner heart leaves, now quickly developing as a ball-like structure of overlapping leaves, are concealed by the surrounding larger leaves. These leaves do not press tightly against the developing head and will later unfold to become frame leaves.
Stage 8	Head fill	Head diameter will be approximately 10 - 20 cm. A firm round head is visible within the wrapper leaves (the 4 outer loose leaves that touch the mature head). The head has not yet fully developed and thus, is not of harvestable size.
Stage 9	Mature	Head diameter will be approximately 15 - 30 cm. No new visible leaf production will occur after the head has attained maximum hardness and size. The head is ready for harvest and may split if not harvested in time.

(Andaloro *et al.*, 1983)

Plant Density

Planting density has an effect on crop production and susceptibility to diseases. The wider the density, the more area one plant has to grow and the more nutrients are available to the plant. The cabbage head size can be regulatcd by adjustment of the planting density (Tindall, 1993 and Nonnecke, 1989), more space and nutrients usually result in larger plants with bigger heads. This can be both an advantage and a disadvantage, depending on market requirements. Despite the larger head size, the overall production of an area with a low planting density may still be low because there is less plant. Planting density also has an effect on the climate within the crop. In a close planting, wind and sunshine cannot reach to the soil level and as a result, the lower leavcs of the crop stay wet longer. This can stimulate disease infcction because many diseases need water to infect the plant.

Table 2 Some factors relatcd to plant spacing

Narrow spacing	**Wide spacing**
more plants per area = higher initial costs	fewer plants per area = lower initial costs
small plants	larger plants
more, but smaller size, heads	fewer, but larger size heads
might increase disease incidence	might reduce disease incidence

Mulching

Mulching means keeping the soil surface covered with non-transparent material. Mulching is used to conserve moisture and increase yields they are also used to insure clean fruit, control weeds, hasten maturity, conserve soil fertility and control of pest and diseases (Mcellum, 1968; Hanada, 1991 and Ramakrishna *et al.*, 2006). Cost of production is reduced in weeding. Water requirements are minimized since evaporation is reduced with mulched plots. Plots are totally covered with the use of plastic mulch, thus the soil is safe from erosion. In uncovered soils, the tendency for leaching is apparent especially during heavy rains and summer. With the use of plastic mulch all of these are controlled. There are many reports confirming the stimulation of growth and consequent yield increases by thc use of plastic mulches (Hanada,

1991). There is a free circulation of air within the plots since the soil is not compact therefore improving soil aeration. Because of the characteristics of the plastic mulch to reflect light, some insect pests are ward off away from the plants. Insect pests can't resist the reflection of light from the sun. Viruses are carried by some insect pests that attack the plants. When the insect pests are repelled, naturally the occurrence of virus attack is greatly minimized. Vos *et al.* (1995) reported that the use of silvery plastic mulch reduced thrips injury and damaged virus epidemic thus having a positive effect on crop health therefore improving crop production.

Drainage

The most important water management practice is providing drainage to keep soil around roots from becoming waterlogged. Seed and seedlings are likely to rot in wet soil. When soil remains wet and muddy during the rainy season, the plants will grow slower and head formation may be hampered. Some diseases can easily spread with the ground water and attack a weakened plant. When the soil tends to stay too wet, dig some trenches to help dewatering. Growing the plants on raised beds and/or plastic covered beds may also help to keep the soil moisture down.

Irrigation

Proper irrigation can be critical for maintaining high yields and quality. Soils with adequate organic matter usually have a large water absorption capacity and do not need frequent irrigation. Soil type does not affect the total amount of water needed, but it does influence frequency of water application. Lighter soils need more frequent water applications, but less water applied per application. Sandy soils may require water at more frequent intervals as water drains off quicker. Over watering can cause heads to burst due to high turgor pressure; the early maturing varieties are particularly vulnerable (Guerena, 2006).

Dixon, 2007 reported that efficient water management is a prerequisite to nitrogen management. He further stated that nitrate nitrogen leaching can be minimized by matching irrigation applications to evapo-transpiration (ET) need. Improved product quality is greater on soils with higher water-holding capacity, but soil type has less effect than nitrogen fertilizer (Nilsson, 1980).

Cabbage is intermediately susceptible to water stress, with the head formation stage more sensitive than the preceding growth periods (Smittle, 1994). Water stress is critical in the period of 3-4 weeks before harvest. Crops irrigated when the soil moisture tension is <25 kPa at 10 cm produced the highest total and marketable yields (Dixon, 2007).

Harvesting

Isenberg *et al.* (1975) suggested predicting the maturity of cabbage heads by using methods of heat unit accumulation. This method is however not commonly practiced. Estimates of maturity still remain subjective and empirical, based on visual assessment and finger tests for firmness (Dixon, 2007). Heads should be firm-to-hard at harvest, but delaying harvest may increase the risk of splitting mature heads if soil moisture increases suddenly. Harvest maturity is also based on head compactness and firmness (Figure 1). A firm or compact head is regarded as a mature head. A compact head can be only slightly compressed when applying moderate pressure with the finger tip. A very loose head is immature and should not be harvested (Figure 2). Harvest maturity may also be based on arrangement of the wrapper leaves; when most of them are tightly attached to each other then it is usually mature. A mature cabbage has a well-developed head and good weight in comparison to its size. Mature cabbage has a longer postharvest life than immature cabbage (NGMC, 2004).

Heads are cut at the base and the outer leaves are trimmed off. For the fresh market, fields may be cut 3 to 5 times. When hybrid varieties are used, a higher percentage of the plants can be harvested at one time. Cabbages are generally ready for harvesting between 62 to 110 days from transplanting (Smith, 2010) depending of cultivars. On an average cabbage yields about 19 to 55 tonnes per hectare (Ogbodo *et al.*, 2011 and Smith, 2010) depending on varieties and the management practices implemented in the field.

Figure 1 Mature compact cabbage head ready for harvest.

(Source: NGMC, 2004)

Figure 2. Immature loosely compact cabbage head.

Post Harvest Handling & Storage

Cabbage heads should be harvested as soon as mature to avoid cracking of heads. The heads must be cooled immediately after harvest. Damaged or diseased wrapper leaves should be removed during grading. Heads with insect damage and other defects should be discarded. Proper hygiene should be maintained during the handling process. Early crop can be stored at 0°C and 98-100% relative humidity for 3 to 6 weeks while late crop can be stored under same conditions for 5 to 6 months (Smith, 2010). Storage life can be prolonged under refrigeration in nitrogen atmosphere modified with 2-6% carbon dioxide and 1-5% oxygen (Dixon, 2000) where available. Bacterial soft rot is the main problem in storage of cabbages.

Nutrient Contents and Health Benefits

Cabbages are nutrient-packed and low in calorie. It is impressive with its high content levels of calcium, iron, iodine, potassium, sulfur, and phosphorus. In the vitamins department, it is loaded with vitamins A, B1, B2, B6, C, E, K and folic acid. They are rich source of a number of phytonutrients which help boost our defense mechanisms, blocks the reaction of cancer-causing substances, detoxifies and eliminates harmful toxins and hormones, and stimulates production of antibodies to fight cancer. There is a growing body of epidemiological and experimental evidence showing that the consumption of *Brassica* vegetables specifically reduces

the risk of cancer in the human lung and alimentary tract (Chu *et.al.*, 2002; Lester, 2006). The health benefits of *Brassica* vegetables are related to their content of glucosinolates (Dixon, 2000).

Insect Pests of Cabbage

Cabbage insect pest is one of the major production hindrances to quality and yield. The greatest insect problem for growers is the Diamond Back Moth (*Plutella xylostella*). Apart from this there are a number of other pests such as cabbage lopper, flea beetle, aphids, cluster caterpillar, centre grub and cut worms that needs to be controlled for efficient production.

Diamond Back Moth (*Plutella xylotella*)

The most devastating pest that causes severe damage in cabbage production is the diamond back moth (DBM) (Kwartery and Towler, 1994). In recent years, crucifer production in tropical and subtropical regions has been seriously affected by populations that have developed resistance to a wide range of insecticides (Tabashnik *et al.*, 1990 and Shelton *et al.*, 1993). The main reason for diamondback moth status as a major pest is its ability to rapidly develop resistance to virtually all insecticides used to control it (Hill and Foster, 2000). Normally, the diamondback moth takes about 32 days to develop from egg to adult. However, the time to complete a generation may vary from 21 to 51 days depending on weather and food conditions (FAO, 2000). There may be several generations per growing season. Generations usually overlap and all four life stages may be present in the field at the same time. The adult moth is approximately 8 to 9 mm long with a wing span of 12-15 mm (FAO, 2000). The folded wings flare upwards and outward at the tips. The wing tips are fringed with longhairs. In the male, the forewing margins have a series of yellow wavy markings. When the wings are folded while the moth is at rest, these markings come together to form three yellow diamonds hence the name diamondback. Adult females lay an average of 160 eggs during their life span of about 16 days (FAO, 2000). Egg-laying occurs at night. The greatest numbers of eggs are laid the first night after emergence and egg-laying continues for about 10 days.

Diamondback moth eggs are oval and flattened, and measure 0.44 mm long and 0.26 mm wide (Capinera, 2001) which are yellow or pale green in color. They are glued to the

upper and lower leaf surfaces singly or in groups of two or three, usually along the veins or where the leaf surface is uneven. The eggs hatch in about five or six days. Immediately after hatching from the egg, larvae burrow into the leaf and begin mining the leaf tissue internally. After feeding within the leaf for about a week, the larvae exit from the underside of the leaf and begin feeding externally. The larvae are pale yellowish-green to green caterpillars covered with fine, scattered, erect hairs. The posterior end of the caterpillar is forked. The diamondback moth larva is easily identified by its peculiar reaction to being disturbed. It will wriggle backward violently and may drop from the plant, suspended by a silken thread (Capinera, 2001 and FAO, 2000). After several seconds, the larva will climb back onto the leaf and continue feeding. Larvae pupate in delicate, white, open-mesh cocoons attached to the leaves, stems or seed pods of the host plant. Initially, the pupae are light green but as they mature, they become brown as the adult moth becomes visible through the cocoon. The pupal stage lasts from five to 15 days, depending on environmental conditions.

Cabbage Looper (*Trichoplusis ni*)

Cabbage looper eggs are hemispherical in shape, with the flat side affixed to foliage. They are deposited singly on either the upper or lower surface of the leaf, although clusters of six to seven eggs are not uncommon (Capinera, 2005). The eggs are yellowish white or greenish in color, bear longitudinal ridges, and measure about 0.6 mm in diameter and 0.4 mm in height (FAO, 2000). Eggs hatch in about two, three, and five days at 32, 27, and 20°C, respectively, but require nearly 10 days at 15°C (Jackson *et al.*, 1969). Young larvae initially are dusky white, but become pale green as they commence feeding on foliage. They are somewhat hairy initially, but the number of hairs decreases rapidly as larvae mature. Larvae have three pairs of prolegs, and crawl by arching their back to form a loop and then projecting the front section of the body forward. The mature larva is predominantly green, but is usually marked with a distinct white stripe on each side. The thoracic legs and head capsule are usually pale green or brown. Dorsally, the larva bears several narrow, faint white stripes clustered into two broad white bands. In some cases the mature larva is entirely green. The body is narrower at the anterior end, and broadens toward the posterior. It measures 3 to 4 cm in length at maturity. Cabbage looper is easily confused with other loopers, but can be distinguished from most by the presence of small,

nipple-like structures (vestigial prolegs) located ventrally on abdominal segments 3 and 4 (Capinera, 2005).

Flea Beetle (*Phyllotreta albionica*)

The adults are small, hard beetles, have an elongated oval shape with enlarged hind legs and are about 2 mm long by 2.5 mm wide (FAO, 2000). Two species of flea beetles most commonly found on crucifers are the cabbage flea beetle and the striped flea beetle. The cabbage flea bectle is all black with no markings and the striped flea beetle is black with a crooked yellow stripe on each wing cover. Adults are easily disturbed and jump quickly, often traveling considcrable distances. The very small pale yellow eggs are laid in the soil, on leaves or in cavities hollowed out in the stem of the plant. The eggs hatch in about 7 to 14 days. The larvae are small, slender white 'worms' that feed primarily on roots and underground stems of the plant for about 7 to 10 days. The larvae transform to pupae in the soil near the base of the plants on which they have been feeding. Both roots and leaves are attacked by this insect. The adults chew many small holes or pits in the leaves, which make them look as if they have been damaged by fine buckshot (Cranshaw, 2006).

Cluster Caterpillar (*Spodoptera litura*)

Cluster caterpillar is a leaf eating caterpillar that feeds in groups when young. As they grow older the caterpillars feed singly, spreading out to other parts of the plant or to neighboring plants; they chew large holes in the leaves and may tunnel into cabbage hearts. The adults are stout-bodied moths with wingspans of 30 to 45 mm (Hamilton and Toffolon, 2003). The forewings are brownish with cream markings, and the hindwings are white. The females lay their eggs mainly on the undersides of leaves in clusters covered with brown scales from the moths' bodies. About 500 - 2000 eggs per female are deposited in batches of 50 - 200 over a few days period (FAO, 2000). When fully grown the caterpillars are 40 to 50 mm long and are brown, black or grey, with a row of dark, rounded-triangular marks along each side of the back and two pairs of large yellowish or white spots near the head (Hamilton and Toffolon, 2003).

Cotton Bollworm (*Helicoverpa armigera*)

The caterpillars damage a wide range of crops formerly known as Heliothis caterpillar. (Helicoverpa was formerly known as Heliothis caterpillar.). The caterpillars may feed on the outer leaves of young plants or burrow into the hearts of older plants. The moths have wingspans of 30 to 40 mm (Chumakov and Kuznetsova, 2009) and are generally buff to reddish brown, with darker markings, and are often seen flying in crops at dusk. The females lay their dome shaped, yellowish white, 0.5 mm diameter eggs singly on the leaves (Hamilton and Toffolon, 2003) and the caterpillars grow to 40 to 50 mm long. At this size they are green, yellow, pink, reddish brown or almost black, often with a broad yellowish white stripe along each side of the body and a dark-edged whitish line down the middle of the back. They have conspicuous body hairs on tubercles. When fully grown the caterpillars pupate in the soil. Emergence of the moths from pupae in the soil depends on the soil moisture content. Thus crops are more likely to be attacked after a period of rain.

Cut Worms (*Agrotis spp.)*

Larvae are usually active during the night and spend the day hiding in the litter or in the soil. They can be found to a depth of up to 12 cm (FAO, 2000). The caterpillars have three pairs of true legs just behind the head and five pairs of false legs in the middle and last part of the body. Cutworm caterpillars curl up when disturbed. The larvae of the black cutworm (*Agrotis ipsilon*) are brown-black in color, with a pale gray band along the mid-line and dark stripes along the sides. The head is very dark with two white spots. The general appearance of the caterpillar is greasy and black in color. A mature caterpillar is 25-50 mm long (Hamilton and Toffolon, 2003). The larval development takes 28 - 34 days, depending on the temperature. The first two instars feed in groups on the leaves of plants, the third instar becomes solitary and becomes a real cutworm (sometimes even has cannibalistic habits). The pupa of the black cutworm is dark red-brown and about 20 mm long. Pupation takes 10 - 30 days depending on temperature. Adults are large, dark moths with a wingspan of 40 - 50 mm (FAO, 2000), with a gray body. Forewings are pale brown in color with a dark brown-black pattern of markings.

Aphids (*Brevicoryne brassicae*)

The intensity of aphid epidemic is regulated by the prevailing weather (Dixon, 2007). In warm dry conditions, there is rapid and extensive eolony growth, while eool damp weather inhibits population expansion (Blackman and Eastop, 1984; Minks and Harrewijn, 1987). Aphids feed by large numbers sucking the sap and that causes wilting and stunting in young plants and yellowing, curling and leaf distortion in older plants. This pest is most prevalent in the drier months. The adult aphid is about 2.5 mm long (FAO, 2000), soft-bodied, grayish with a mealy covering, and may be winged or wingless. The immature stages resemble the wingless adults. They cluster densely on the leaves are important vectors of virus diseases.

Cabbage White Butterfly (*Pieris rapae*)

Caterpillar of *Pieris brassicae* are pale green in color at first, but they rapidly become mottled blue-green,with many black markings. When fully grown, each eaterpillar is 30 mm long (Hamilton and Toffolon, 2003) and has three yellow colored lines down the back, and yellow along the sides of the body (FAO, 2000). Each has groups of short, stiff, white hairs along the body. Caterpillars tend to stay together in small groups. The caterpillars eat the leaves and defoliate the plants and contaminate them with large quantities of feces. In heavy infestations leaves are reduced to the midribs and the plants are killed. The larvae feed on the first formed outer leaves of their host plants, which often appear riddled with irregularly shaped holes. As the caterpillars become mature, they feed in the center of the plant. Their excretions can be found between the leaves. The moths are about 9 mm long and grayish brown, with a series of diamond-shaped markings on the centre-line of the back when the moth is at rest (Hamilton and Toffolon, 2003).

Diseases of Cabbage

Cabbage and leafy greens are susceptible to a number of diseases that may seriously injure or even destroy the crop. Some diseases may cause only minor spotting, but because the leaves are consumed, the quality may be reduced below market standards. Prevention is the key to controlling all diseases affecting crucifers.

Black-rot (*Xanthomonas campestris* pv. *Campestris*)

Black-rot is caused by bacteria. The bacterium attacks many species of the mustard family. Plants may be affected at any stage of growth. This disease is seedborne (Walker, 1952) and is often introduced by contaminated seeds or infected transplants. In some cases, the crop may be destroyed. In the field, the disease is easily recognized by the presence of large yellow to yellow-orange V-shaped lesions extending inward from the margin of the leaf. Bacteria are spread by splashing or running water, wind-blown rain, by blowing of detached leaves, cultivating implements and infected seedlings (FAO, 2000).When infected seeds germinate, the resulting young plants usually die quickly; however, these plants serve as an inoculum source for other plants. If infection occurs in young seedlings, the disease is much more severe because the main stem becomes infected and the disease becomes systemic and moves throughout the plant. These plants remain stunted and the veins in the stem are black. Heads developed from these plants deteriorate rapidly after harvest. The disease is most severe under warm and wet conditions. The pathogen can survive in soil even on plant debris for only 1-2 growing season (Dixon, 2007).

Sclerotinose (*Sclerotinia sclerotiorium)*

Sclerotinose is common in cabbage fields as well as transplant beds and greenhouses. The disease usually begins on the lower stem, causing a watery soft rot followed by white, cotton like growth. Black sclerotia, overwintering structures that give rise to the spore producing apothecia, develop later. The disease is favored by cool, wet weather, which may result in a massive steam like cloud of spores being spread throughout an area. The disease can infect cabbage from the seedling stage to maturity. On mature cabbage, the entire head is often covered with the white mycelium and black sclerotia, sometimes referred to as "raisin head." The entire heads melt down, basically leaving a pile of sclerotia. Plants with heavily infected stems will wilt and fall over, eventually dying (Aerts and Mossler, 2004). Sclerotinose often follows cold conditions or other types of plant injury (Kucharek, 2004). The remarkable thing about this disease is that it does not cause any odor during the destructive process unless other saprophytic organisms invade, which do cause odor. The best defense against this disease is to transplant

disease-free transplants and cultivate to cover any sclerotia. Dixon, 2007 reported that sclerotial survival was reduced significantly by plastic covering.

Damping-off in seedbeds (*Fusarium, Rhizoctonia, Pythium, Phytophthora sp.*)

A number of species of soil-dwelling fungi, including *Fusarium, Rhizoctonia, Pythium* and *Phytophthora sp.*, infect vegetables, especially crucifers. Species of *Pythium* are more common than the others. If the infection occurs either before (pre-emergence) or just after emergence (post-emergence), and development of a spot (lesion) at the soil line results in collapse and shriveling of the plant, the disease is called 'damping-off'. Infection occurs just around the soil line in young seedlings. Damping-off occurs in transplant seedbeds. Plants either fail to emerge, or in the case of post-emergence damping-off, a water-soaked lesion develops on the stem at or just below the soil surface. The seedling later wilts, falls over, and then dies (Kucharek, 2004). The dry rot is usually limited to the outer part of the stem and infected plants may fall down or may remain more or less upright. Infected plants remain under-developed and usually die (FAO, 2000).

Soft rot (*Erwinia carotovora*)

The common name of this bacterial disease arises from the characteristic soft decay of the fleshy tissue of the plant. When soft rot affects a plant, the tissue softens, becomes watery and slimy. Cabbage plants give off a distinctive sulfurous odor (FAO, 2000). The disease can be found on crops in the field, transit, and storage or during marketing; resulting in great economic losses. Soft rot causes greater total loss of produce than any other bacterial disease (Bhat *et al.*, 2010). Affected heads decay rapidly and turn dark. The bacteria survive in soil on decaying and dead plant debris. Wounds are the most common entry point for this bacterium. The infection can occur through surface areas like leaves injured by insects or mechanical means or through damaged roots or stems. Bacteria spread through the veins to other plant parts. Warm wet conditions favour disease development. Soft rot bacteria can grow over a temperature range of 5-35 °C with an optimum temperature of about 22 °C (AVRDC, 2001). Abundant moisture at the surface of the plant tissue often increases the chance of invasion by pathogens. After infection has taken place, high relative humidity increases the severity of the disease.

The Concept of Good Agricultural Practice

Fresh Fruits and Vegetable export continue to face a growing number of quality and food safety requirements in international markets. These include increasingly stringent regulations concerning the use of agrochemicals and their maximum residue levels (MRLs), as well as voluntary standards set by private sectors. Increasing attention recently is also being focused upon the impact farming practices have on the environment. There has been an increasing emphasis on more sustainable methods of crop production. Systems need to be adopted that are more sensitive to environmental issues, genetic diversity, wildlife and their habitats and in some cases the social structures of rural communities (Coresta, 2005). Consumers around the world have become critically concerned than in the past, demanding to know the method and practices used to produce their agriculturally derived products.

Good Agricultural Practices (GAP) are "practices that address environmental, economic and social sustainability for on-farm processes, and result in safe and quality food and non-food agricultural products" (FAO, 2003). From the time of planting a crop until its consumption, there are many opportunities for contamination with harmful microorganisms, pesticides and other toxic substances. On the farm, soil, manure, water, animals, equipment, and workers may spread such contaminants. Produce may be harvested on a farm, processed in one plant, repackaged in another, then stored, displayed, or served commercially or in the home. Each of these steps is an opportunity for harmful contamination of the food supply (Bashour, no date). A multiplicity of GAP codes, standards and regulations have been developed in recent years by the food industry and producers organizations but also governments and NGOs, aiming to codify agricultural practices at farm level for a range of commodities. Their purpose varies from fulfillment of trade and government regulatory requirements (in particular with regard to food safety and quality), to more specific requirements of specialty or niche markets. The objectivc of these GAP codes, standards and regulations include, to a varying degree: ensuring safety and quality of produce in the food chain, capturing new market advantages by modifying supply chain governance, improving natural resources use, workers health and working conditions and creating new market opportunities for farmers and exporters in developing countries (FAO, 2003). The development and implementation of codes for good agricultural practices (GAP) that reflect

national development priorities and conditions can bring benefits to developing countries by promoting the production of safe and healthy foods, improving workers' health and safety, and reducing environmental impacts (APEC, 2006).

The four 'pillars' of GAP (economic viability, environmental sustainability, social acceptability and food safety and quality) are included in most private and public sector standards, but the scope which they actually cover varies widely (FAO, 2008). The concept of Good Agricultural Practices may serve as a reference tool for deciding, at each step in the production process, on practices and/or outcomes that are environmentally sustainable and socially acceptable. The implementation of GAP should therefore contribute to sustainable agriculture and rural development.

Some of the potential benefits of GAP as identified by FAO, (2008) are that appropriate adoption and monitoring of GAP helps improve the safety and quality of food and other agricultural products. It may help reduce the risk of non-compliance with national and international regulations, standards and guidelines (in particular of the Codex Alimentarius Commission, World Organisation for Animal Health (OIE) and the International Plant Protection Convention IPPC) regarding permitted pesticides, maximum levels of contaminants (including pesticides, veterinary drugs, radionuclide and mycotoxins) in food and non-food agricultural products, as well as other chemical, microbiological and physical contamination hazards. Adoption of GAP helps promote sustainable agriculture and contributes to meeting national and international environment and social development objectives.

The challenges related to GAP identified in the same report suggests that in some cases GAP implementation and especially record keeping and certification will increase production costs. In this respect, lack of harmonization between existing GAP-related schemes and availability of affordable certification systems has often led to increased confusion and certification costs for farmers and exporters. Standards of GAP can be used to serve competing interests of specific stakeholders in agri-food supply chains by modifying supplier-buyer relations. There is a high risk that small scale farmers will not be able to seize export market opportunities unless they are adequately informed, technically prepared and organized to meet this new challenge with governments and public agencies playing a facilitating role. Creating awareness is needed of 'win-win' practices which lead to improvements in terms of yield and

production efficiencies as well as environment and health and safety of workers. One such approach is Integrated Production and Pest Management (IPPM).

International Standards

GLOBAL GAP formerly known as EurepGAP is a private sector body that sets voluntary standards for the certification of production processes of agricultural (including aquaculture) products around the globe. The GLOBAL GAP standard is primarily designed to reassure consumers about how food is produced on the farm by minimizing detrimental environmental impacts of farming operations, reducing the use of chemical inputs and ensuring a responsible approach to worker health and safety as well as animal welfare. It serves as a practical manual for Good Agricultural Practice (GAP) anywhere in the world. The basis is an equal partnership of agricultural producers and retailers who wish to establish efficient certification standards and procedures (GLOBAL GAP, 2009).

GLOBALGAP therefore addresses consumer concerns on food safety, environmental protection, worker health, safety and welfare and animal welfare through encouraging adoption of commercially viable farm assurance schemes, which promote the minimization of agrochemical and medicinal inputs, within Europe and worldwide, developing a Good Agricultural Practice framework for benchmarking existing assurance schemes and standards including traceability, providing guidance for continuous improvement and the development and understanding of best practice, establishing a single, recognized framework for independent verification and communication and consulting openly with consumers and key partners, ineluding producers, exporters and importers.

Good Agricultural Practice therefore addresses issues of proper nutrient management, appropriate pest control systems with emphasis of the types of pesticides used resulting in acceptable MRL and proper handling of produce to eliminate microbial contamination and maintain high hygiene standards.

Codex Alimentarius

The Codex Alimentarius Commission was created in 1963 by FAO and WHO to develop food standards, guidelines and related texts sueh as codes of practice under the Joint

FAO/WHO Food Standards Programme. The main purposes of this Programme are protecting health of the consumers and ensuring fair trade practices in the food trade, and promoting coordination of all food standards work undertaken by international governmental and non-governmental organizations. It has over 170 member countries within the framework of the Joint FAO/WHO Food Standards Programme established by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) (FAO and WHO, 2011). The Commission is therefore responsible for establishing a system of guidelines, standards and recommendations that guides the direction of the global food supply ensuring food safety for all.

Codex is comprised of over 40 committees, task forces and expert groups which deal with nearly every facet of food production. Codex's remit covers almost all areas of the food supply, ranging from cereals, cocoa, dairy, meat, meat hygiene, sugars and fresh fruit and vegetables to more controversial issues such as food labeling, food additives, contaminants in food, pesticide residues and genetically modified organisms (GMOs). Committee meetings are hosted by particular national governments and held either in the host country or another part of the world. All Codex country members are permitted to attend each annual meeting or 'session' and the meeting is facilitated and closely managed by the Committee's chair and secretariat. Decision-making in committee meetings is by consensus among governments. International Non Governmental Organizations are not allowed to vote, but they can certainly interject during meetings and therefore have the potential to influence decisions.

Integrated Nutrient Management

Integrated nutrient management for sustainable crop production is focused on the effective management of all nutrient sources to optimize crop production and environmental sustainability around the world (Aulakh and Grant, 2008). Nutrient management is a process that involves defining the nutrient needs of crops, and determining the best method to provide the amount, sources, placement and timing of fertilizer and manure applications to maximize nutrient uptake of the crop, and improve yields. Long term security of the global food supply requires a balance between increasing crop production and environmental sustainability. Nutrient surpluses and nutrient excesses can threaten both crop productivity and environmental sustainability

(Aulakh and Grant, 2008). Integrated nutrient management aims to provide the necessary nutrients to the crop while also improving the physical and biological soil properties. Furthermore, this practice tends to minimize nutrient losses to the environment (Maene *et al.*, 2008). Implementation of nutrient management plans should protect the environment, maintain crop productivity, and increase profitability (Crouse, 2011). Nutrient imbalances in the soil and plant tissues lead to toxicity and deficiency syndromes that impair growth, resulting in stress disorders and the development of off-flavors in the harvested produce (Dixon, 2007). Therefore due to these reasons it is important that fertilizers are applied after establishing the available quantities already present in the soil and demand the growing crop imposes. Willie, (2007) reported that the combined use of organic and inorganic fertilizers significantly increased yields when compared with the sole fertilizers.

There are 17 essential nutrients required for plant growth: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl) and nickel (Ni). Of these 17, all except carbon, hydrogen, and oxygen are derived from the soil (Rosen and Eliason, 2000). In situations where the soil is not able to supply the level of nutrient required for adequate growth, supplementary fertilizer applications becomes necessary. Soil testing prior to planting is therefore important and leads to more efficient nutrient management.

Soil Test

A soil test is a chemical or physical measurement of soil properties based on a sample of soil (Jones and Steyn, 1973). It is considered as a rapid chemical analysis or quick test to assess the readily extractable chemical elements of a soil. Interpretations of soil tests provide assessments of the amount of available nutrients, which plants may absorb from the soil (Barker and Pilbeam, 2008). Soil samples submitted for analysis should be representative of the field or portion of a field. Therefore, by sampling from an area of the field where yield is typically average, soil test results should come back with an average representation of the field.

Use of Synthetic Fertilizers

There are a number of environmental issues related to fertilizer use, including soil acidification and the accumulation of naturally occurring impurities in soils to which fertilizers are applied (Maene, *et al.*, 2008). Characteristics of inorganic synthetic fertilizers are that they dissolve in water and are immediately available to the plant for uptake. When used according to recommendations, these types of fertilizers are safe for the environment and can supply the required nutrients for plant growth. However, excessive rates of these fertilizers can injure the roots of plants causing death and potentially lead to environmental degradation (Rosen and Eliason, 2009). Improving agricultural productivity is vital for poor rural households in the developing countries to meet their food security needs and to promote sustained increases in income. Inorganic fertilizer can be a powerful productivity enhancing input (Juliet, 2008) if responsibly used. The application of inorganic fertilizers has been widely observed to increase the crop yields (Rasool, *et al.*, 2008). The inorganic fertilizers affect soil physical environment by increasing the above ground and root biomass due to immediate supply of plant nutrients in sufficient quantities (Lopez-perez *et al.*, 1990). This in turn increases the soil organic matter content (Haynes and Naidu, 1998; Sarkar *et al.*, 2003; Bostick *et al.*, 2007). The inorganic fertilizers have been reported to increase rooting depth and root proliferation in cereals (Belford *et al.*, 1987; Brown *et al.*, 1987).

Garcia-Gimeno *et al.*, 1996 reported the contribution of heavy metals to the soil from using inorganic fertilizers. Superphosphate is the fertilizer that contains the highest concentrations of Cadmium (Cd), Cobalt (Co), Copper (Cu) and Zinc (Zn) as impurities. Copper sulphate and iron sulphate have the most significant concentrations of Lead (Pb), and are the only fertilizers in which Nickel (Ni) was detected (Gracia-Gimeno *et al.*, 1996). Cadmium (Cd), Mercury (Hg), Lead (Pb), Arsenic (As), Cobalt (Co), Molybdenum (Mo) and Selenium (Se) pose human health risks at plant tissue concentrations that are not generally phytotoxic, leading to greater potential for entry into the food chain (MeLaughlin *et al.*, 1999; Dhillion and Dhillon, 1997, 2003).

Inorganic fertilizers have contributed immensely to world food production. Global food production has increased drastically over the past forty years due to higher fertilizer use and improved plant nutrition management practices (Maene, *et al.*, 2007). Harvesting of crops

also takes away the nutrients in the soil thus contributing to soil fertility degradation. External supplies need to be applied in order to prevent this degradation. Synthetic fertilizers will continue to play an important role to reduce the world hunger to fulfill the Millennium Development Goal by 2015 and beyond.

Use of Organic Fertilizers

Increased consumer awareness of food safety issues and environmental concerns has contributed to the development of organic farming over the last few years (Worthington, 1998; Worthington, 2001; Relf *et al.*, 2002). Organic fertilizer is an effective agent for improving soil quality in the long term (Boonsiri *et al.*, 2009). They are made up of larger molecules and substances that take time to be broken down into forms usable by the plant. Compost made from animal manure and various plant residues is often used as an organic soil amendment and nutrient source. The composting process stabilizes available nitrogen into less available forms. Thus, compost and most organic fertilizers can be considered slow-release type fertilizers with a low salt index. Therefore, they can be applied in larger amounts at one time without causing injury to the plant root. For organic nitrogen sources (except urea), one application can be made without having to be concerned with losing all the nitrogen to leaching. Unless an animal operation is nearby, organic fertilizers are usually more expensive and bulkier than inorganic sources (Rosen and Eliason, 2009). Organic applications increased nutrient status, microbial activity and productive potential of soil (Kang *et al.*, 2005), promoting soil structure formation (Reganold *et al.*, 1987; Pulleman *et al.*, 2003), enhancing soil biodiversity (Doles *et al.*, 2001; Mader *et al.*, 2002) and alleviating environmental stresses (Horrigan *et al.*, 2002).

While organic fertilizers have positive effects on the soil and the general environment, it however risks food contamination. Contamination can arise as a consequence of treating soil with organic fertilizers such as manure and sewage sludge (EC, 2002) if not handled properly. As animal manures are used as fertilizer for organically grown fruit and vegetables, the potential for microbial contamination is higher than for conventionally grown crops (Raicevic *et al.*, 2010).

Organic agriculture respects the normal functioning of ecosystems, avoiding the use of agrochemicals, and leads to food "free" of synthetic chemicals and, thus, more healthy.

Notwithstanding the health value of better quality agriculture products, organic agriculture does not appear to have the potential for mass production of the amount of calories needed to feed humanity. The development of organic agriculture may, therefore, contribute to improved food safety but does not help to cope with food security (Carvalho, 2006).

Manure Management

Animal manure should be well stored and managed in an environmental sustainable manner to avoid environmental and food contamination. Some of the facts manure include:

1. Animal manure can contain bacteria such as *Salmonella, Campylobacter* and *E. coli* O157:H7, as well as parasites like roundworms and tapeworms.

2. Persons most likely to be seriously harmed by manure pathogens include pregnant women, the elderly, infants and children and the immune-compromised.

3. Animal manure can be used as an effective fertilizer and soil amendment but it should not be allowed to contaminate foods which are consumed uncooked, such as fresh fruits and vegetables.

4. Store manure away from areas where fresh produce is grown and handled. Use distance or physical barriers to prevent runoff or wind drift of manure. Prevent cross-contamination by tools or farm equipment.

5. When growing fresh fruits and vegetables, adequately composting animal manure is the most effective practice.

6. In addition to composting animal manures other manure management practices can be used including field-applying manure shortly after harvesting and incorporating the manure into the soil as soon as possible.

Pesticide

Globally, approximately half of all food and fiber produced is lost to field and storage pests (Pimentel, 1997). Crop protection is probably the most limiting factor in crop production. The wide range of pests that attack crops during the various stages of growth from

seed to fruit necessitate the application of various means of pest control. Farmers have depended mainly on the use of pesticides to combat the multitude of pests. The use of pesticides, including insecticides, fungicides, herbicides, rodenticides, etc., to protect crops from pests, allowed to significantly reduce the losses and to improve the yield of crops such as corn, maize, vegetables, potatoes, cotton, as well as to protect cattle from diseases and ticks and to protect humans from malaria vectors (Carvalho, 2006). The world has known a continuous growth of pesticide usage, both in number of chemicals and quantities, sprayed over the fields. Pesticides are poisons intentionally dispersed in the environment to control pests, but they also act upon other species causing serious side effects on non-target species. Residues of pesticides contaminate soils and water, remain in the crops, enter the food chain, and finally are ingested by humans with foodstuffs and water (Barcelo′ and Hennion, 1997; Taylor *et al.*, 2003). Therefore, residues of pesticide could affect the ultimate consumer's health especially when freshly consumed (Zhang *et al.*, 2006).

Sanborn *et al.* (2004) conducted a preview of the effects of pesticides on human health and reported that exposure to all the commonly used pesticides, phenoxyherbicides, organophoshates, carbamates and pyrethrins are associated with adverse health effects. They report the work of various researchers. Triazine herbicide increased breast cancer risk (Hopenhayn-Rice *et al.*, 2002). Carbamate and phenoxyherbicide exposure increased lung cancer risk (Pesatori *et al.*, 1994). Spraying of an organophosphate during pregnancy caused deterioration of placentas (Levario-Carillo *et al.*, 2001). Indoor use of insecticides was associated with brain cancer and acute lymphocytic leukemia in children (Pogoda and Preston, 1997; Infarite-Rivard *et al.*, 1999). Pesticides such as 2, 4-D and dicamba are associated with increased time to pregnancy (Arbuckle *et al.*, 1997). Fungicide exposure had positive association with dermatitis (Cole *et al.*, 1997; Paulsen, 1998; Rademaker, 1998). Azmi *et al.*, (2006) also reported clinical effects such as hepatitis, dyspnea and burning sensation in urine due to prolonged periods of exposure to pesticides. Recent reports have indicated a strong link between male infertility and exposure to more than 50 pesticides (Cox, 1996).

Many studies reported that the main pesticide residues were organophosphates and pyrethroids (Bai *et al.*, 2006; Shen *et al.*, 2002; Sun *et al.*, 2003), and organochlorine and its derivatives etc. (Kumari *et al.*, 2002; Lakwah *et al.*, 1995). Some methods and equipments were

developed to decrease or remove pesticide residues in agroproduces, such as washing, refrigeration, peeling, ozone treatment, cooking etc. (Li *et al.*, 2004; Moya *et al.*, 1998; Yu *et al.*, 2005; Zhang *et al.*, 2004; Prasad and Chetty, 2008).

The developed countries go in the direction of fewer chemicals and more green products, promoting the production of new pesticides that are less persistent and are often costly. The developing countries need to increase the agricultural production and the use of crop protection chemicals seems a simple way for obtaining better crop yields. This practice however contributes to contamination of environment, exposure of the public and residues in food are higher with a higher risk to human health.

To lower the risk to consumers due to the pesticide residue in food products, standards for pesticide residues were developed, a particularly important element of which concerned the Maximum Residue Limit (MRL) for pesticides permitted on specific foods. The Maximum Residue Limit (MRL) is the maximum concentration of residues in a product considered by the authorities as without sanitary hazard for the consumer and without effect on the manufacturing processes. MRL for different pesticides have been established as a reference point to ensure the consumers are getting safe food.

Poramacom, 2001 reported the work of Yentongchai *et al.* (1995) who examined the organophosphorus insecticides in Chinese Kale. Thirty Chinese Kale samples obtained from the market in Thailand were contaminated by methamidophos, diazinon, monocrotophos, and profenofos which were exceeded the Codex MRL or had reached the hazard level. Cherdchu, (2010) also reported that from a sample of 492 vegetables exported from Thailand to EU countries in 2010, 33.1 % of vegetables tested had MRL more than the recommended levels.

Elbetieha and Sahar, (2003) reported a significant reduction in fertility of male rats when ingested with abamectin at the rate of 1.19, 1.87 and 2.13 mg/animal/day. The exposed males had an increase in the weight of testes, decreased testicular sperm count and daily sperm production. The testes revealed several abnormalities including infiltration with congested blood vessels with marked hemorrhage (Elbetieha and Sahar, 2003).

Methods of Pest Control

Insect pests are one of the major contributors for yield losses in crops. Diamondback moth now occurs wherever crucifers are grown, and control of the pest worldwide is estimated to cost US$1 billion each year (Talekar and Shelton, 1993). Losses of cabbage and cauliflower due to the moth can reach 90% without the use of insecticides (Verkerk and Wright 1996). Even when insecticides are used, the losses can be substantial. In tropical areas where pest pressure is high, it is not uncommon for insecticides to be applied every other day, posing hazards to farmers, consumers and the environment (Uijtewaal, 2006). Not all organisms are pests and a majority of them are beneficial to the global society and environment. Many examples exist that document the environmental and health risks from the indiscriminate use of pesticides (Maredia *et al.*, 2003). Pests have a remarkable capacity to adapt to several control agents. Development of resistance in insect pests to control methods using resistant plant varieties, cultural or biological controls, insect controlling pathogens and insecticides are common. More than 4000 examples of resistance to insecticide have been documented in populations of about 500 species of insects (Sarfaraz *et al.*, 2005).

Pest Control in Organic Farming System

Organic farming is a method of farming which involves the use of ecologically friendly techniques to raise crops and animals. Many nations offer organic certification to farmers who follow organic farming guidelines, and farmers can also practice organic methods without pursuing certification. This farming method is viewed as an alternative to conventional agriculture, in which a wide variety of means are utilized in farming. When farmers work organically, they avoid the use of synthetic chemicals for everything from soil management to pest control. Instead, they rely on techniques like crop rotation and composting to keep soils healthy, natural pest control rather than sprays to eliminate agricultural pests, and non-chemical means to control infections and disease. Full organic standards vary from nation to nation, with departments of agriculture usually maintaining current standards in publicly available databases (Smith, 2010).

Organic agricultural method is internationally and legally enforced by many nations based in large part on the standards set by the IFOAM (International Federation of Organic Agriculture Movements); an international umbrella organization for organic organizations established in 1972. *Bacillus thuringiensis* (BT) is a naturally occurring soil bacterium that causes disease on insect pests. It is accepted as an alternative in organic farming and is considered ideal for pest management because it is host specific and is non-toxic on natural enemies and on humans. BT is commercially available in most agricultural suppliers. It is sold in various formulations (spray, dust, and granule) and strains (*Bt tenebrionis, Bt kurstaki, Bt israelensis, Bt aizawai, Bt san diego*). An insect pest must ingest BT before it is killed. When BT is ingested, it produces proteins that react with the cells of the stomach lining. These (proteins) poison and paralyze the insect's digestive system causing the insect to stop feeding within hours. A BT-infested insect will live for several days but will cause no further damage to the plant. It will die eventually from starvation.

Pest Control in Conventional Farming System

Conventional farming refers to farming systems where synthetic fertilizers and pesticides are commonly used to cultivate crops. Pesticides are widely used to protect the crops from a variety of pests. The use of pesticide benefits in increasing agricultural production but the repeated and indiscriminate uses of certain pesticides have led to their accumulation in plants, animals, solid and sediments, thus effecting widespread contamination of the environment. Such application of pesticides has the drawback of pesticide residues which remain on fruits and vegetables, constituting a potential risk to consumers. Fruits and vegetables are the foods that receive the highest doses of pesticides (Torres *et al.*, 1996). Overuse, misuse and improper use of pesticides endanger health of farm workers and consumers of agricultural products worldwide (Goodell, 1984).

Insecticides used to control insect pests that feed on crops or carry plant diseases prevent huge losses. Tatchell (1989) estimated that aphids and the virus diseases they spread would cause £120 million in the UK without control measures being applied.

Thailand is one of the biggest users of pesticides in the South Asia region. Most pesticides are imported, and foreign companies hold the biggest market share. Of the pesticides

that are imported, 73% fall into World Health Organization categories Ia (extremely hazardous) and Ib (highly hazardous). The three main insecticides in use are the organophosphates monocrotophos, methamidophos and methyl parathion, all considered particularly hazardous under conditions of use in developing countries (PANUPS, 1997).

According to the Thailand National Statistical Office; fifth Agricultural Census conducted in 2003, 54.4% of holdings surveyed, reported of using pesticides, of which 45.9% used chemical and only 3.4% reported using organic. The majority of holdings using pesticides was in the Central and Northern Region (76.5 and 73.3% respectively), while the holdings in the Northeastern and Southern Region used pesticides 44.9 and 32.9% only.

Abamectin belongs to the family of avermectins, a class of macrocyclic lactones produced by a soil actinomycete, streptomices avermitils (Pozo *et al.*, 2003). Abamectin is a mixture of avermectins containing about 80% avermectin B1a and 20% avermectin B1b (Elbetieha and Sahar, 2003). Avermectins are one of the most common active compounds applied as veterinary drugs for food producing animals, specially, in aquaculture and as plant protection agents in the agricultural sector (Hernando *et al.*, 2007). It acts as an insecticide by affecting the nervous system of and paralyzing insects (Elbetieha and Sahar, 2003). From the regulatory point of view, the maximum concentrations allowed in food and vegetables are given by Maximum Residual Level (MRL) (Pozo *et al.*, 2003). The MRL vegetables for abamectin as per Codex Alimentarius is only provided for lettuce leaf at 0.05 mg/kg (FAO and WHO, 2005). However, the MRL for abamectin as approved by Public Health Ministry of Thailand for Brassica vegetables is 0.01 mg/kg (TFDA, 2009).

Biological Pest Control

Biological control of insects is the use of natural enemies (parasitoids, predators and pathogens) to reduce or maintain insect pest populations below an economic, action or aesthetic threshold (DeBach and Rosen, 1991; Bellows and Fischer, 1999). The practice of biological control includes methods that reunite pests with their natural enemies, or recommend modifications of the environment (or the natural enemy itself) to favor natural enemy population growth and impact on pest dynamic. (Maredia *et al.*, 2003).

Pests and their natural enemies are living organisms which move between habitats searching for the resources in order to survive, grow and reproduce. Many farmers apply pesticides without considering the pest's lifecycle or their impact on other organisms. In the search for alternatives to chemical pesticides, more emphasis is placed on the natural control of pests using cultural and biological means (Maredia *et al.*, 2003). The habitat surrounding crops plays an important role in supporting and sustaining important natural enemies (Maredia *et al.*, 1992; Landis *et al.*, 2000). Key components of the system are biological control, cover crops and mixed cropping to provide an alternate resource base for the pest controlling organisms, crop rotation and sanitation of crop residue (Maredia *et al.*, 2003).

The diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is one of the most destructive cosmopolitan pests of cruciferous crops (Talekar and Shelton). This pest is now present wherever its host plants exist and is considered to be the most widely distributed of all Lepidoptera (Shelton, 2004). Although over 130 parasitoid species are known to attack various life stages of DBM, most control worldwide is achieved by relatively few hymenopteran species belonging to the ichneumonid genera *Diadegma* and *Diadromus*, the braconid genera *Microplitis* and *Cotesia* , and the eulophid genus *Oomyzus* (Sarfaraz *et al.*, 2005; Liu *et al.*, 2000; Kirk *et al.*, 2004).

Integrated Pest Management System (IPM)

Integrated Pest Management (IPM) is a system approach to the design, use and continued evaluation of pest management procedures that result in favourable socioeconomic and environmental consequences (Isley, 1957; Ruesink, 1976; Bird *et al.*, 1990). IPM means the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms (FAO, 2002). It is an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This

information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property, and the environment. Control of pest population is achieved using techniques such as enhancing natural enemies, planting pest resistant crops, cultural management and using pesticides as a last resort (Lesile and Cuperus, 1993; Maredia and Mihm, 1994; Maredia, 1997).

IPM is not a single pest control method but, rather, a series of pest management evaluations, decisions and controls. In practicing IPM, growers who are aware of the potential for pest infestation follow a four-tiered approach. The four steps include:

Set Action Thresholds

Before taking any pest control action, IPM first sets an action threshold, a point at which pest populations or environmental conditions indicate that pest control action must be taken. Sighting a single pest may not always mean that control is needed. The level at which pests will either become an economic threat is critical to guide future pest control decisions.

Monitor and Identify Pests

Not all insects, weeds, and other living organisms require control. Many organisms are innocuous, and some are even beneficial. IPM programs work to monitor for pests and identify them accurately, so that appropriate control decisions can be made in conjunction with action thresholds. This monitoring and identification removes the possibility that pesticides will be used when they are not really needed or that the wrong kind of pesticide will be used.

Prevention

As a first line of pest control, IPM programs work to manage the crop, lawn, or indoor space to prevent pests from becoming a threat. In an agricultural crop, this may mean using cultural methods, such as rotating between different crops, selecting pest-resistant varieties, and planting pest-free rootstock. These control methods can be very effective and cost-efficient and present little to no risk to people or the environment.

Control

Once monitoring, identification, and action thresholds indicate that pest control is required, and preventive methods are no longer effective or available, IPM programs then evaluate the proper control method both for effectiveness and risk. Effective, less *risky* pest controls are chosen first, including highly targeted chemicals, such as pheromones to disrupt pest mating, or mechanical control, such as trapping or weeding. If further monitoring, identifications and action thresholds indicate that less risky controls are not working, then additional pest control methods would be employed, such as targeted spraying of pesticides. Broadcast spraying of non-specific pesticides is a last resort.

IPM strategies are different for each crop, for a country, for a region, even for one location, depending on local varieties used and local agronomic practices. IPM can never be delivered in a "package"; it needs to be developed, adapted, tailor-made to fit local requirements. Yet, experiences from one area or from other countries may be helpful to set up field studies for testing the components that may lead to tolerable pest populations and a high yield of good quality produce (FAO, 2000).

Nitrate Contents in Vegetables

Nitrogen is the most abundant element in our atmosphere. It is a primary nutrient for all green plants, but it must be modified before it can be readily utilized by most living systems. It is one of the elements that are widely used to boost production of leafy vegetables around the world. Nitrate is a naturally occurring form of nitrogen and is an integral part of the nitrogen cycle in the environment (Santamaria, 2008). Nitrate uptake and distribution in crops is of major importance with respect to both environmental concerns and the quality of crop products. Nitrate, not taken up by a crop, may potentially contribute to ground and surface water pollution through nitrate leaching and soil erosion (Gastal and Lemaire, 2002; Wang *et al.*, 2002). Due to the increased usage of nitrogen based fertilizers to produce vegetables and pasture, there may be an increased concentration of nitrates in the crops and the drinking water. The presence of nitrate in vegetables, as in water and generally in other foods, is a serious threat to man's health (Santamaria, 2008). The main concern for the public health is the link between nitrates and

stomach cancer (Prasad and Chetty, 2008). Shao-ting *et al.*, 2007 reported the work of some previous researches suggesting that the vegetables with high nitrate in the diet could put a human into the risk of gastrointestinal cancer and methemoglobinaemia. Nitrate itself is relatively non-toxic but its metabolites, nitrite, is associated with methaemoglobinaemia. Nitrite might also react with amines to form carcinogenic nitrosamines in the stomach (EFSA, 2008). Nitrate predominately enters the human body exogenously from vegetables, water, and other foods, but is also formed to a limited extent endogenously (Lundberg *et al.*, 2004 and 2008). Nitrates in the soil are a primary source of nitrogen which is essential for plant growth. Due to the increased use of synthetic nitrogen fertilizers and livestock manure in intensive agriculture, vegetables and drinking water may contain higher concentrations of nitrate than in the past (Santamaria, 2008).

Spinach, lettuce, broccoli, cabbage, celery, radish, beetroot, etc. possess the tendency to accumulate nitrate (Prasad and Chetty, 1998). Nitrogen is essential to the nutrition and function of plants, so plants exert a close metabolic control on the concentration of nitrate and other nitrogen compounds. Nitrate is mainly to be found in cell vacuoles and is transported in the xylem. The xylem carries water and nutrients from the roots to the leaves, whereas the phloem carries the products of photosynthesis from the leaves to the growth points of the plant. This affects the distribution of nitrate between the leaves and storage organs such as seeds or tubers. This means that leaf crops such as cabbage, lettuce and spinach have fairly large nitrate concentrations whereas storage organs such as potato tubers, carrots, leeks, onions, seeds and pods of pea and bean plants have relatively small concentrations (EFSA, 2008).

Another consequence of the transport system is that young leaves have lower nitrate concentration than older leaves. Such a relation was shown for cabbage with greatest nitrate concentrations in the outer leaves and much smaller nitrate concentration in the innermost leaves (Greenwood and Hunt, 1986). Nitrate moves from the bulk soil to the root surface mainly by convection rather than diffusion, so shortage of water will restrict nitrate uptake. Excess soil water dilutes the nitrate in the soil solution and can make the soil anoxic, thereby restricting crop growth and causing loss of nitrate by denitrification. Soil type and mineral content can affect nitrate accumulation (EFSA, 2008).

The coupling of nitrogen assimilation and photosynthetic electron transport in leaves implics that light intensity is the key factor in determining nitrate concentrations in leaf

crops. Month to month differences in light intensity caused as much as threefold variations in nitrate concentrations in lettuce grown in Western Europe (Van Eysinga, 1984). Winter-sown crops have generally higher nitrate concentration than summer crops in the same environment and Northern European crops have higher nitrate levels compared to Southern European crops (Weightman *et al.*, 2006). These differences can be explained by both higher irradiance in summer which tends to reduce nitrate, and also to higher growth rates which coincide with periods of high irradiance and warmer temperatures (Kanaan and Economakis, 1992). The maximisation of light availability influences also the level of nitrate when crops are produced under glasshouse conditions (Premuzic *et al.*, 2002). Nitrogen fertilization and light intensity have been identified as the major factors that influence nitrate content in vegetables. Vegetables are easy to concentrate nitrate and excessive applieation of nitrogen increases nitrate accumulation in vegetables (Du *et al.*, 2011).

Table 3 Classification of vegetables according to NO_3^- content (mg/kg)

Very low (<200)	Low (200-500)	Middle (500-1000)	High (1000-2500)	Very High (>2500)
Artichokes	Broccoli	Cabbage	Celeriac	Celery
Asparagus	Carrot	Dill	Chinese Cabbage	Chervil
Broad Bean	Cauliflower	Savoy Cabbage	Endive	Cress
Brussel Sprouts	Cucumber	Turnip	Fennel	Lettuce
Eggplant	Pumpkin		Kohlrabi	Radish
Garlic	Chicory		Leaf Chicory	Rocket
Onion			Leek	
Greenbean			Parsely	
Melon				
Mushroom				
Pea				
Potato				
Tomato				

Source: Santamaria, (2006)

Acceptable Daily Intake (ADI)

The concept of ADI is defined by the Joint Expert Committee of the Food and Agriculture (JECFA) Organization of the United Nations/World Health Organization (WHO) for substances intentionally added to food or for contaminants (pesticides, herbicides and fertilizers) (Speijers *et al.*, 2003). Santamaria, (2006) in her review paper on nitrate has cited various sources on the JECFA and the European Commission's Scientific Committee on Food (SCF) established ADI for NO_3 to be 0-3.7 mg/kg of body weight (bw). She further reports the USA Environment Protection Agency (EPA) Reference Dose (RfD) for nitrate to be 1.6 mg nitrate/kg bw per day (equivalent to about 7.0 mg NO_3 per kg bw per day).

Table 4 Maximum levels (limits) of NO_3^- (mg/kg) to trade various vegetables in some European countries

Vegetable	Austria	Belgium	Germany	Netherlands	Switzerland
Carrot	1500				
Red beetroot	4500		3000	3500	3500
Endive (summer)	2500	2000		2500	2500
Indivia (winter)	3500	2000		3500	2500
Cabbage	1500				
Radish		3500			
Celery (green)		5000			
Celery (white)		4000			
Lamb's lettuce		3500	2500		

Source: Santamaria (2006).

Food Safety

Food hazards can enter the food supply at any point from farm to table. Many food borne hazards cannot be detected in food when it is purchased or consumed. These hazards include microbial pathogens and chemical contaminants. In addition, a food itself can cause

severe adverse reactions. Food borne diseases cause significant illness and death worldwide through the ingestion of food contaminated by bacteria, viruses, parasites, chemicals and biotoxins (WHO, 2011). Sources of food contamination are almost as numerous and varied as the contaminants themselves. Bacteria and other infectious organisms are pervasive in the environment. Bacteria (occasionally pathogenic) inhabit the surfaces of fruits and vegetables in the field. Molds and their toxic byproducts can develop in grains during unusually wet or dry growing seasons, damage and stress during harvesting, or during improper storage. Foods may become contaminated during processing due to malfunctioning or improperly sanitized equipment; misuse of cleaning materials; rodent and insect infestations; and improper storage. Foods may become contaminated in retail facilities and in the home through use of poor food handling practices (EPA, 2011).

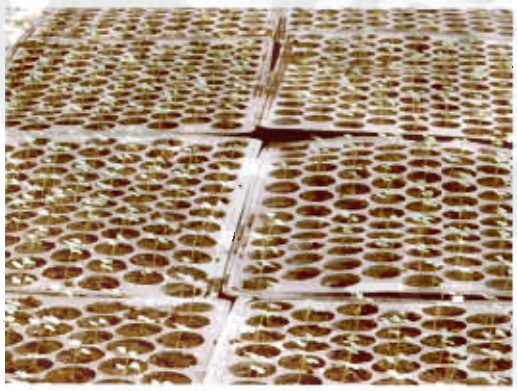
Microbiological criteria of food quality are considered of great importance due to the significance of public health and safety. Contamination of fruits and vegetables can arise as a result of presence of microorganisms as bacteria, viruses and parasites. Microbial contamination depends on different factors including soil conditions that could be the reservoir of foodborne pathogens as *Bacillus cereus* or water for irrigation. Water may be source of different pathogens such as *Salmonella spp.*, or *E. coli* O157:H7. They could be transferred from water to the fruits or vegetables. Organic fertilizers (sewage sludge, animal manure, compost) may also be potential risk for contamination of fruits or vegetable. Fruits and vegetables could also be contaminated during harvest (due to the lack of sanitary facilities to workers or dirty storage capacity) or post harvest treatment (handling, storage and transportation). Therefore, to minimize the risk of infection or intoxication associated with raw fruits and vegetables, potential sources of contamination from the environment should be identified and specific measures and interventions to prevent and/or minimize the risk of contamination should be considered and correctly implemented (Raicevic *et al.*, 2010).

CHAPTER 3

MATERIALS AND METHOD

Raising of cabbage seedlings

Head cabbage, *Brassica oleracrea* L. var. *capitata* (2n = 18) of family Brassicaceae was used in the experiment. 30 g seed (1 packet) of the variety F1 hybrid C3557 produced by Chia Tai Seeds, Thailand was used for the experiment. Eighteen seedling trays with 105 cups per tray were filled with potting mix purchased from the agricultural store in Maejo. Two cabbage seeds were sown per cup and thoroughly watered and placed on the benches on 3rd of November, 2010. The nursery had sufficient light trespassing to ensure good germination of the seeds. The seedling trays were watered every day with a watering can to ensure sufficient moisture for good germination. Eighty percent of germination was recorded on the sixth day after sowing. The seedlings were thinned to allow one seedling per cup to achieve healthy seedlings for transplanting. Watering was done every day and the growth and development of the seedling was closely monitored (Fig. 3). *Bacillus thuringiensis* at the rate of 20 ml in 5 liters of water was applied to the seedlings one week before transplanting. Seedlings were transplanted at the appearance of 3 to 4 true leaves 4 weeks after sowing on 04/12/2010.



(A) 1 week seedlings sown in nursery trays filled with media

(B) 2 weeks old seedling in the nursery

(C) 3 weeks old seedling in the nursery

(D) 4 weeks seedling ready for transplanting

Figure 3 Cabbage seedlings in the nursery

Soil sampling and analysis

Soil samples from 0-15 cm depth of the field were collected 3 weeks before transplanting of the seedlings for analysis of Nitrogen (N), Phosphorus (P), Potassium (K) nutrient contents, organic matter content and soil pH at the Department of Soil Resources and Environment Laboratory, Maejo University. The experimental area was marked and soil sample was randomly taken in a zig zag manner covering the whole marked area. The extracted samples were then mixed together and a composite sample of about 400 grams ware taken from the mixed lot for analysis. The results of the soil analysis of trial field are presented in Table (5). The % carbon was obtained by dividing % OM content by 2, as practised by Jakse and Mihelic (1999). While % N was calculated by multiplying % OM with 0.05.

Determination of total N in soil by Kjeldahl Method

Total N was determined by the Kjeldahl method (AOAC, 1984). In the presence of H_2SO_4, potassium sulfate (K_2SO_4) and catalyst cupric sulfate ($CuSO_4$), amino nitrogen of many organic materials was converted to ammonium. Free ammonia also converted to ammonium. After addition of base, the ammonia was distilled from an alkaline medium and absorbed in boric acid. The ammonia was determined colorimetrically by titration with a standard mineral acid.

%N = nHCl x f HCl x (ml HCl – ml Blank) x 0.014 x 100/Ws

Where: n = Normality of HCl, f = Standarization factor, Ws = Weight of sample.

Determination of available phosphorus in soil

Available P in the soil was determined by extracting P using Bray 2 solution as extractant (Matt, 1970). The extracted phosphorus was measured by colorimetric method, based on the reaction with ammonium molybdate and development of the 'Molybdenum Blue' colour. The absorbance of the compound was measured at 882 nm in a spectrophotometer and was directly proportional to the amount of phosphorus extracted from the soil.

Available P in soil in ppm = (ppm in solution – ppm blank) x 25/5 x 20/Ws

Where: Ws = weight of soil sample.

Determination of exchangeable potassium in soil

Exchangeable K in the soil was determined by the method described by van Reeuwijk (1987). 2.5 g soil was shaken for 1 hour with 50 mL of 0.05M hydrochloric acid. After settling overnight to clear solution, an aliquot was diluted for potassium determination by atomic absorption.

Ppm K in soil = (ppm solution – ppm blank) x 100/Ws x df

Where: Ws = Weight of soil sample; df = dilution factor

Table 5 Result of soil analysis of the experimental field

Soil Sample	pH	%OM	%N	Available – P (ppm)	Extractable forms (ppm)
					K
1	7.75	0.9	0.045	783	121

Field experiment

Experiment location

The field experiment was conducted in the Vegetables Research and Development Experimental farm, Vegetable Division of Faculty of Agricultural Production, Maejo University. The university is about 300 m above sea level in Chiang Mai Province north of Thailand located at latitude 17° 15′ N - 20° 16′ N and longitude 98° 03′ E - 99° 33′ E. The soil type of field was sandy clay and the field had been under continuous crop production for student projects. The previous crop in the experimental area was okra. The field trial was planted on 4th of November, 2010 and continued until mid of February, 2011. Two experiments; first to determine the effect of nitrogen and plant spacing while the second to determine the best pest control methods were conducted simultaneously.

Field preparation and layout

The field was ploughed once and rotovated to give a fine tilth to the soil. Experimental plots were marked and 20 cm high raised beds which was 1.0 m in width made using a hoe. The beds were flatten using a garden rake and all weeds removed. The raised beds were then covered with sliver coloured plastic mulch (Fig. 4) to conserve moisture and prevent weed growth before transplanting of the seedlings.

(A) Field marking of plots

(B) Raised beds made

(C) Beds covered with plastic mulch

(D) 4 weeks old seedlings transplanted

Figure 4 Field preparations.

Experiment 1 – Effect of nitrogen and plant spacing on growth, yield, quality and food safety of cabbage

Treatment application

Poultry manure at the rate of 200 grams and compost at the rate of 50 grams per m^2 was applied in the plots 2 weeks before transplanting. Phosphorus at the rate of 14 kg per rai (30.4 kg per rai of 0-46-0) and Potassium at the rate of 36 kg per rai (72 kg per rai of 0-0-50) was also applied as basal application in the plots prior to transplanting. From the total N (N1; 14 kg N per rai (30.4 kg urea/rai {46-0-0}), N2; 16 kg N per rai (34.8 kg urea/rai {46-0-0}) and N3; 18 kg N per rai (39.1 kg urea/rai {46-0-0}); 50% (15.2, 17.4 and 19.6 kg urea {46-0-0} per rai) was respectively applied as basal in the main plots and mixed with the soil according to treatment specifications before covering the beds with plastic mulch. The remaining 50% of nitrogen was

applied in the main plots 20 days after transplanting as side dressing and the plants were watered. Planting holes were made using a hole maker acquired from the vegetable division. Three different plant spacings (50 cm between rows x 30 cm within rows, 50 cm between rows x 40 cm within rows and 50 cm between rows x 50 cm within rows) were used in the experiment.

There were a total of 36 plots in the experiment covering a total trial area of 297.5 m^2. The size of each plot was 5 m^2 (5 x 1 m). Each plot had two rows with varying number of plants as per treatment specifications. The in-field variability for fertility, moisture and sunshine gradients were considered in laying the experimental design. The longer length of each plot was oriented in north-south direction. The experiment was laid out in randomized complete block design (RCBD) with split plot arrangement with the nitrogen levels as main plots and plant spacing as sub plots consisting of 12 treatments with three replications as outlined below:

N = Nitrogen

D = Plant Spacing

Treatment 1 N0 (0kg N/rai) D1 (50 x 30cm)

Treatment 2 N0 (0kg N/rai) D2 (50 x 40cm)

Treatment 3 N0 (0kg N/rai) D3 (50 x 50cm)

Treatment 4 N1 (14kg N/rai) D1 (50 x 30cm)

Treatment 5 N1 (14kg N/rai) D2 (50 x 40cm)

Treatment 6 N1 (14kg N/rai) D3 (50 x 50cm)

Treatment 7 N2 (16kg N/rai) D1 (50 x 30cm)

Treatment 8 N2 (16kg N/rai) D2 (50 x 40cm)

Treatment 9 N2 (16kg N/rai) D3 (50 x 50cm)

Treatment 10 N3 (18kg N/rai D1 (50 x 30cm)

Treatment 11 N3 (18kg N/rai) D2 (50 x 40cm)

Treatment 12 N3 (18kg N/rai) D3 (50 x 50cm)

14kg N/rai = 30.4 kg urea/rai (46-0-0)

16kg N/rai = 34.8 kg urea/rai (46-0-0)

18kg N/rai = 39.1 kg urea/rai (46-0-0)

D1 (50 x 30cm) = 32 plants

D2 (50 x 40cm) = 26 plants

D3 (50 x 50cm) = 20 plants

Crop management

All the plots received equal amounts of water. Manual irrigation using a watering can was done daily in the morning and also in the afternoon during the entire cropping cycle. Weeds grown in the furrows were removed using a hoe once at 37 DAT. The growth and development of the plants were closely monitored.

Insect pest control

The beds were first sprayed with Nematode (*Steinernema carpocapsae*) at the rate of 75 grams in 20 liters of water per rai (468.74 grams per hectare) or 0.23 grams per plot as basal before covering the beds with plastic mulch. Yellow sticking traps were placed every 3 to 4 meters apart in the entire experimental block. The trial plots were closely monitored for insect pest infestation on a weekly basis. Three sprayings of *Bacillus thuringiensis* var. *kurstaki* were done on 16 DAT, 30 DAT and 47 DAT and one spraying of Abamectin was done on 38 DAT as alternative for pest resistant management.

Measurement of plant height and leaf length and width

Ten plants from each plot were randomly selected (5 plants from each row) and marked as sample plants for measurement of plant height, leaf length and width on weekly basis. These ten plants in each plot were also used later for determination of frame leaves, stem diameter, wrapper leaves, head width, head height, biological yield and economic yield at harvest. The border plants located at the end of the rows were not included in sampling. The plant height was recorded by measuring from the base of the plant stem at ground level to the tip of the tallest

leaf with a calibrated plastic ruler. The leaf length was measured along the mid rib from the base of the leaf to the tip on a vertical position and leaf width was measured while stretching the leaf across from one end to another on a horizontal position with a calibrated plastic ruler.

Measurement of yield and yield components

Measurement of stem diameter

The stem diameter was measured at the middle of the stem length with Mitutoyo digital vernier caliper at the harvest of the crop. The same ten plants from each plot which were earlier included in the sampling for measurement of plant height and leaf length and width were selected for determination of stem diameter.

Measurement of number for frame and wrapper leaves of cabbage head

The frame leaves were recorded at harvest by counting all the loose leaves in a plant that did not form head. The frame leaves of all 10 sample plants were counted and recorded. However, only three heads of cabbage were randomly selected from 10 plants in each plot at harvest to count wrapper leaves. The wrapper leaves were recorded by removing all the leaves in a head, starting from the outermost and finishing at the innermost core of head consisting of only miniature leaf primordium.

Measurement of head width and head height

Three heads per treatment were randomly selected to measure the head length and width using a Mitutoyo digital vernier caliper. The heads were sliced from the middle and the head height was measured from the base of the head to the tip holding the head in a vertical position while the head width was measured from one side of the head to the other keeping the head in a horizontal position with the sliced part facing upwards (Fig. 5).

(A) Measurement of head height

(B) Measurement of head width

Figure 5 Measurement of head height and width

Determination of head firmness of cabbage

The firmness (solidity) of the head of 10 sample plants was measured by hand held Penetrometer using 8 mm (½ cm^2) plunger tip (Fig. 6). The penetrometer reading was set at zero kg by adjusting its knob. Cabbage head was then firmly held horizontally with left hand on the table and the plunger was placed against the surface of the head. A steady downward pressure at right angle was applied until the plunger just penetrated the flesh of the cabbage head. The plunger was removed from the cabbage and the reading on the penetrometer dial was noted. Then the process was repeated on the opposite side of the cabbage head after first setting the reading on penetrometer at zero. The average of two readings was used for recording the head firmness.

(A) A penetrometer used to measure head firmness

Figure 6 Measuring head firmness

Determination of biological yield and economic yield of cabbage

Harvesting of cabbage commenced on 1st of February, 2012 when 50 % heads in the experimental block were mature. The head maturity was determined by the hardness of the heads when the tip of the head was pressed with fingers. The ten sample plants from each plot which were selected for determination of biological and economic yield of cabbage were harvested by cutting the base of the plant below the last frame leaves.

The biological weight (weight of head + weight of frame leaves) of the cabbage on fresh weight basis was determined by weighing both frame leaves and head together in a portable Camry platform weighing scale (Fig. 7). Similarly, the economic weight (head weight) of cabbage on fresh weight basis was determined by removing all the outer frame leaves and loose leaves on the head and only the weight of intact head with firm wrapper leaves were recorded as economic yield in a portable Camry platform weighing scale (Fig. 7).

(A) Biological weight (B) Economical weight

Figure 7 Measuring weight of heads to determine yield

Determination of unmarketable yields

The percentage of unmarketable yields (not suitable for export) was determined by individually weighing each head and discarding all heads that were 1.1 kg and less. An average percentage was then worked out representing total unmarketable heads per treatment.

Determination of quality

Determination of dry matter content and total soluble solids

Three heads of cabbage were randomly selected at harvest from plot to determine dry matter content (% DM) and total soluble solid (TSS) content (% Brix). The three selected heads from each treatment were chopped into slices and mixed together and composite sample from the mixture was selected, filled in a plastic bag and labeled before taking to the laboratory at the Faculty of science at Maejo University. A sample of 100g from each plot was accurately measured using a digital weighing scale and placed in a weighed petri dish and recorded as fresh weight. The petri dishes were labeled and put in an oven tray which was kept in Hot Air Oven (Memmert) at 70°C for 48 hours. The samples were weighed after 48 hours and the dry matter content (% DM) of the samples were recorded by subtracting the final weight from the weight of the petri dish.

For determination of TSS, three head selected from each treatment were sliced into very fine pieces and a composite sample from each treatment was selected and the juice was extracted by squeezing it in a muslin cloth. The extracted juice was used to determine the TSS by using a LCD Digital Hand Refractometer (Atago, PAL-1, Japan). The refractometer was first calibrated to zero reading by putting several drops of distilled water on the prism surface and the corresponding reading was adjusted to zero. The prism surface was dried by wiping with tissue paper. 2-3 drops of filtered cabbage juice was placed on clean and dry prism plate of LCD Digital Hand Refractometer and the corresponding reading was recorded. Three readings were taken for each treatment sample. The prism plate of LCD Digital Hand Refractometer was washed with distilled water and dried with tissue paper every time before placing the sample juice. The room temperature during the determination of TSS with Refractometer was set at 22° C.

Figure 8 LCD Digital Hand Refractometer (Atago, PAL-1, Japan) used in the determination of TSS of cabbage.

Determination of nitrate contents in cabbage

Three heads of cabbage randomly selected from each treatment at harvest were chopped and mixed together. A composite sample of 300 grams was selected and packed in airtight ploy bags before taking it for the analysis at the Institute of Product Quality and Standardization, Maejo University by In-house AOAC Official Method 976.14 (AOAC, 2000b) as described below:

1. Sample preparation.

The coded sample was blended in electric grinder until it was finely ground. 10 g sample was transferred to 200 ml volumetric flask. 70 ml of de-ionized water (DI), 10 ml $ZnSO_4.7H_2O$ and 12 ml NaOH were added to the flask containing 10 g sample. To the recovery flask 1 ml of standard sodium nitrate solution was also added in addition to the reagents used for sample. After keeping these two flasks in water bath at 50° C for 10 minutes, they were cooled at room temperature and diluted to 200 ml with DI. Then the solutions were filtered through Whatman No 1 filter (125 mm diameter) into volumetric flasks. The first 20 ml each of filtrate from two flasks was discarded. After that 80 ml of each filtrate were collected in Erlenmeyer flasks and their mouths were covered with parafilm of 4 inch x 125 feet dimension.

2. Coating of cadmium with copper in modified Jones Reductor.

30 g of 5-20 mesh cadmium was first washed with 6N HCl and then with water. After that the cadmium balls were kept in 100 ml of 2% $CuSO_4$ for 5 minutes with constant stirring till blue colour of $CuSO_4$ disappeared. The $CuSO_4$ solution was discarded and new $CuSO_4$ solution was added until brown precipitate was obtained. Then the cadmium coated with Cu was washed 10 times to remove $CuSO_4$ precipitates.

3. Determination of nitrate in sample

30 g of cadmium balls was placed in Jones Reductor column and 15 ml of 0.1 N HCl passed through the column. The column was further cleaned by running 15 ml of DI water for 2 times followed by 15 ml buffer solution. The solution thus collected was discarded. The 5 ml buffer solution followed by 5 ml sample solution and 25 ml DI water were run through the column and collected in 50 ml volumetric flask. To the collected solution, 2 ml sulfanilamide and 1 ml NED (N-1-naphthyl ethylene diamine dihydrochloride) were added and left for 20 minutes. The final solution was then diluted to 50 ml with DI water and the optical density of the solution was measured by UV Spectrophotometer (NICOLET evolution 300) at 540 nm wavelength.

NO_2 (mg/kg) = V x C x D/W

Where: C = concentration of nitrite from standard curve (μg/ml),

V = volume of solution before dilution (ml),

D = dilution factor,

W = weight of sample (g).

NO_3 (mg/kg) = (A-B) x 1.348

Where: A = quantity of nitrite in sample passed through column (mg/kg),

B = quantity of nitrite in sample,

1.348 = NO_2 to NO_3 conversion factor.

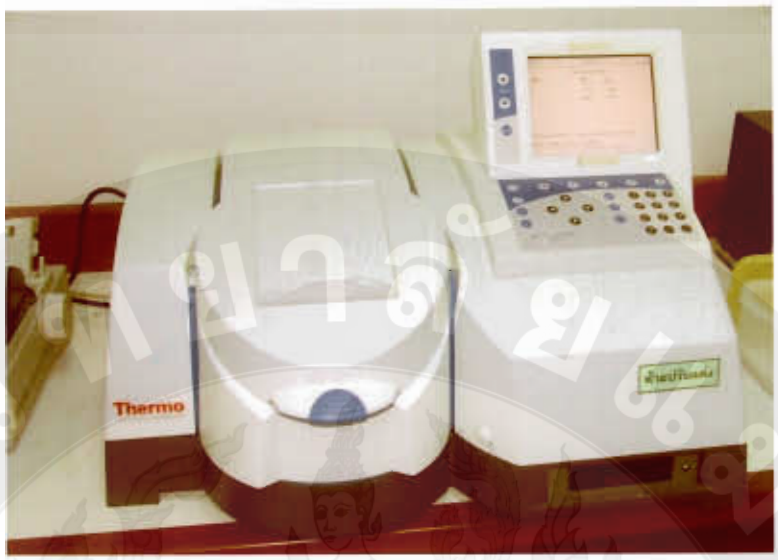


Figure 9 Spectrophotometer (NICOLET Evolution 300 LC, England) used for determination of Nitrate concentration of cabbage leaves.

Experiment 2 – Comparative study of different pest control methods on yield, quality and food safety of cabbage

Treatment application

Poultry manure at the rate of 200 grams and compost at the rate of 50 grams per m^2 was applied in the plots 2 weeks before transplanting. Phosphorus at the rate of 14 kg per rai (30.4 kg per rai of 0-46-0), Potassium at the rate of 36 kg per rai (72 kg per rai of 0-0-50) was also applied as basal application in the plots prior to transplanting. From the total N (14 kg per rai (30.4 kg urea/rai {46-0-0}), 50% (15.2 kg urea/rai{46-0-0}) was applied as basal in plots and mixed with the soil before covering the beds with plastic mulch. The remaining 50% was applied 20 days after transplanting as side dressing and the plants were watered. Planting holes were made using a hole maker at a spacing of 50 cm between rows x 30 cm within rows.

There were a total of 16 plots in the experiment covering a trial area of 82.5 m^2. The size of each plot was 3 m^2 (3 x 1 m). Each plot had two rows with 20 plants per plot. The in-field variability for fertility, moisture and sunshine gradients were considered in laying the experimental design. The longer length of each plot was oriented in north-south direction. The

experiment was laid out in randomized complete block design (RCBD) consisting of 4 treatments with four replications as outlined below:

Treatment 1	Control
Treatment 2	BT
Treatment 3	Abamectin
Treatment 4	Integrated Pest Management

Crop management

All the plots received equal amounts of water. Manual irrigation using a watering can was done daily in the morning and also in the afternoon during the entire cropping cycle. Weeds grown in the furrows were removed using a hoe once at 37 DAT. The growth and development of the plants were closely monitored.

Insect pest control

The IPM plots were first sprayed with parasitic nematode (*Steinernema carpocapsae*) at the rate of 75 grams in 20 liters of water per rai (468.74 grams per hectare) as basal before covering the raised beds with sliver coloured plastic mulch. Yellow sticky traps were placed in the same beds. The trial plots were closely monitored for insect pest on a weekly basis. Four sprayings of *B. thuringiensis* var. *kurstaki* were done on 16 DAT, 30 DAT, 38 DAT and 47 DAT on the BT plots. The IPM plots were sprayed three times with *B. thuringiensis* var. *kurstaki* at 16 DAT, 30 DAT, and 47 DAT and one time with abamectin on 47 DAT as alternative for pest resistant management. The chemical control plots were also sprayed four times with abamectin on 16 DAT, 30 DAT, 38 DAT and 47 DAT. The control plots were only sprayed with water on the same days.

Measurement of yield and yield components

Measurement of number of frame and wrapper leaves of cabbage head

The frame leaves were recorded at harvest by counting all the loose leaves in a plant that did not form head. The frame leaves of all 10 sample plants were counted and recorded. However, only three heads of cabbage were randomly selected from 10 plants in each plot at harvest to count wrapper leaves. The wrapper leaves were recorded by removing all the leaves in a head, starting from the outermost and finishing at the innermost core of head consisting of only miniature leaf primordium.

Measurement of head width and head height

Three heads per treatment were randomly selected to measure the head length and width using a Mitutoyo digital vernier caliper. The heads were sliced from the middle and the head height were measured from the base of the head to the tip holding the head in a vertical position while the head width was measured from one side of the head to the other keeping the head in a horizontal position with the sliced part facing upwards (Fig. 5). The head diameter was then calculated by multiplying the head length with the head width.

Determination of biological yield and economic yield of cabbage

Harvesting of cabbage commenced on 1st of February, 2012 when 50 % heads in the experimental block were mature. The head maturity was determined by the hardness of the heads when the tip of the head was pressed with fingers. The ten sample plants from each plot which were selected for determination of biological and economic yield of cabbage. The plants were harvested by cutting the base of the plant below the last frame leaves.

The biological weight (weight of head + weight of frame leaves) of the cabbage on fresh weight basis was determined by weighing both frame leaves and head together in a

portable Camry platform weighing scale (Fig. 7). Similarly, the economic weight (head weight) of cabbage on fresh weight basis was determined by removing all the outer frames leaves and loose leaves on the head and only the weight of intact head with firm wrapper leaves was recorded as economic yield in a portable Camry platform weighing scale.

Determination of quality

Determination of number of damaged frame and wrapper leaves of cabbage heads

The damaged frame leaves (Fig. 9) were recorded at harvest by counting all the loose leaves in a plant that did not form head and sustained damages on the leaf surface. The damaged frame leaves of all 10 sample plants were counted and recorded. Same 10 sample plants were also selected to count the damaged wrapper leaves by removing and inspecting one leaf after another.

(A) Damaged frame leaf (B) Good frame leaf

Figure 10 Comparison between damaged & good frame leaves

Determination of pest larvae count

The experimental plots were regularly monitored to access the scale of damage sustained in the individual plots. The larvae of the pests which mostly included Diamond Back Moth (*Plutella xylotella*), Cabbage Lopper (*Trichoplusis ni*), White Butterfly (*Pieris rapae*) and Cluster Caterpillar (*Spodoptera litura*) were counted and recorded in the individual plots on a weekly basis.

Determination of pesticide residue in cabbage

Three cabbage heads were randomly selected from the IPM and the chemical control plots which were sprayed with abamectin for the determination of the pesticide residue in the leaves. The samples were harvested at 9 days after the last spraying, filled in an air tight polythene bag and labeled as:

S1 - IPM plot

S2 - Chemical control plot (Abamectin)

The harvested sample was then taken to Pesticide Residue Analytical Laboratory, Plant protection Center, Royal project Foundation, 65 M.1 Suthep Rd., T. Suthep., A. Muang, Chiangmai for analysis. The residues were detected using SPR-0070-V1.0, (2004) determination of abamectin in fruits and vegetables using HPLC with fluorescence detection as follows:

Step 1- Preparation of standards

Stock standard solution (25 μg/ml AVM, Avermectin B_1)

140 mg Abamectin standard glycerol solution was weighed into a 50 ml volumetric flask, dissolved and diluted to volume with acetonitrile. The weight was recorded and the sample stored in freezer at -15 °C.

Working standard solution (5 µg/ml AVM, Avermectin B_1)

10 ml of stock standard solution was transferred to a 50 ml volumetric flask and diluted with acetonitrile and mixed thoroughly. The weight was recorded and the sample stored in the refrigerator at 4 °C.

Calibration standards

0.025, 0.05, 0.1 and 0.15 µg/ml working standard for derivatization was prepared and transferred to separate 15 ml silylated centrifuge of 5 µL, 10 µL, 20 µL and 30 µL respectively. The standards were latter derivated as described in step 4.

Step 2 – Sample Preparation

One kilogram of sample was blended in a food processor for two minutes. The blended sample was then transferred into a large Mason jar prepared for analysis.

Step 3 – Extraction

A 10 gram of the blended sample was weighed into a 50 ml polypropylene conical tube and marked as tube A. To spike a sample recovery, a spiking standard (5 ng/µL AVM) was added to a 10 gram sample and let it stand for 30 minutes at room temperature. Then 2 ml of acetonitrile, 2 ml of water and 10 ml of hexane was added to the sample. Abamectin was then extracted by blending with a ploytron homogenizer for 30 seconds. The probe was then rinsed by blending with 2 ml of water and 10 ml of hexane in a 50 ml conical tube marked as tube B. This rinsed probe was the added to the extracted abamectin sample. A 10 ml of hexane was added to a 50 ml empty conical tube and again the probe was rinsed by blending before using the probe on the next sample. A stopper was placed on the sample and shaken for 1.5 minutes and then centrifuged for 5 minutes at ~ 4000 rpm. A disposable pipet was used to separate and transfer hexane layer into a clean 50 ml conical tube and marked as tube C. The sample from tube B was re-extracted with a 10 ml of hexane. The sample was then again shaken for 1.5 minutes and then centrifuged for 5 minutes at ~ 4000 rpm. The upper layer of the hexane separated and combined together with the hexane layer extracted earlier (approximately 25-30 ml from each sample).

Step 4 – Derivatization

The sample and the prepared standards were taken in a silylated centrifuge tube and dried with nitrogen at 50 to 70°C. The 0.1 ml of NMIM/ACN (1:1) was added to the sample with a graduated pipette. Stopper was placed on the tube which was then sonicated for 30 seconds. The sample and the standard tube were placed in an ice bath for 5 minutes. The sample and the standard tube were removed and 0.15 ml of TFAA/ACN was put into them using a graduated pipet. The tubes were then incubated at 30°C for 10 minutes. After 10 minutes, the tubes were removed and 0.1 ml of methanoli ammonium hydroxide solution was put into it and re-incubated at 30°C for another 10 minutes. The tubes were then removed and the contents were diluted 1 ml with ethanol. 50 µL of each sample was the injected into the HPLC system (Fig. 10). Using linear regression, a standard graph was constructed of four AVM standard concentrations versus peak areas and the slope was calculated. Y intercept and correlation coefficient was calculated using the equation y = mx + b where y = peak area

x = AVM standard concentration (µg/ml)

m = slope

b = y intercept.

From the measured peak area (y) for each sample, AVM sample concentration computed using the equation: Sample concentration in ppm (µg/g) = $(y - b)/m \times 10$

Reporting Limit is 0.003 µg/g. Results below the Reporting Limit were reported as "not detected ".

Figure 11 HPLC machine used for pesticide residual analysis

Cost of production

The cost of production was calculated at the market price of agro-inputs and labour cost during the period of the experiment. The labour man days was estimated based on the man hours engaged in the experiment and converted into rai. Different rates of nitrogen were used as cost combination to calculate the gross margin.

Data analysis

All the data collected in the experiment were statistically analyzed using Statistical Analysis System (SAS) Version 9.0 statistical software program. Analysis of Variance (ANOVA) was used to determine significant differences between treatments in each experiment. Duncan's Multiple Range Test (DMRT) and Least Significant Difference (LSD) at 5% probability were applied to the treatment means comparison where treatments had significant effect.

CHAPTER 4

RESULTS

Experiment 1 – Effects of nitrogen and plant spacing on growth, yield, quality and food safety of cabbage

Vegetative growth

Plant height

The development of plant growth affected by nitrogen and plant spacing as measured on a weekly basis over a period of 7 weeks are presented in figures11 and 12 and Table 6. There were no significant differences at $P < 0.05$ as affected by nitrogen among the treatments for the first 14 DAT. However, significant differences at $P < 0.05$ were observed in the plant height as affected by nitrogen from 21 DAT. The treatment with 16 kg N per rai recorded the highest plant height of 11.27 cm and the treatment with 14 kg N per rai recorded the lowest plant height of 9.78 cm. Treatment with 16 kg N per rai was significantly different at $P < 0.05$ from the treatment with 14 kg N per rai but was however not significantly different at $P < 0.05$ from treatment with 18 kg N per rai and the control plot. Significant differences were also observed among the plant heights as affected by nitrogen on 28 DAT. Treatment with 16 kg N per rai recorded the highest plant height of 14.32 cm while the lowest plant height of 12.60 cm was recorded from the control plot. Treatment with 16 kg N per rai was significantly different at $P < 0.05$ from the control. However, it was not significantly different at $P < 0.05$ from the treatments with 14 and 18 kg N per rai. Significant differences at $P < 0.05$ were also observed in the plant height as affected by nitrogen on 35 DAT. The highest plant of 30.21 cm was recorded in the treatment with 16 kg N per rai and was significantly different at $P < 0.05$ from the smallest plants (27.07 cm) which were recorded in the control plot. There was however no significant difference at $P < 0.05$ level between the treatments having 14, 16 and 18 kg N per rai. Plant height at 42 DAT were significantly different among each other at $P < 0.05$ level. Treatments with 14, 16 and 18 kg N per rai were not significantly different among each other but they were however significantly different from the control at $P < 0.05$ accept for treatment with 16 kg N per rai which

was not significantly different from the control plot. Plant height as affected by nitrogen was highly significantly different at $P < 0.01$ on 48 DAT. There were no significant differences among the treatments applied with nitrogen. However, they were highly significantly different from the control.

No significant differences at $P < 0.05$ were observed in the plant height among the treatments as affected by different plant spacings from 7 to 42 DAT. However, highly significant differences at $P < 0.01$ were observed on 49 DAT. The tallest plants were observed in the treatments with plant spacing of 50 cm between rows x 30 cm within rows while the shortest plants were observed in the spacing of 50 cm between rows x 50 cm within rows. There was no significant difference among the plant spacing of 50 cm x 30 cm with 50 cm x 40 cm and 50 cm x 40 cm with 50 cm x 50 cm. Significant differences at $P < 0.01$ were however observed among the plant spacing of 50 cm x 30 cm with the plant spacing of 50 cm x 50 cm. With the earlier having the tallest plant and the latter have the shortest plants in the whole experiment. No significant interaction was observed in the plant height between rates of nitrogen and different plant spacing.

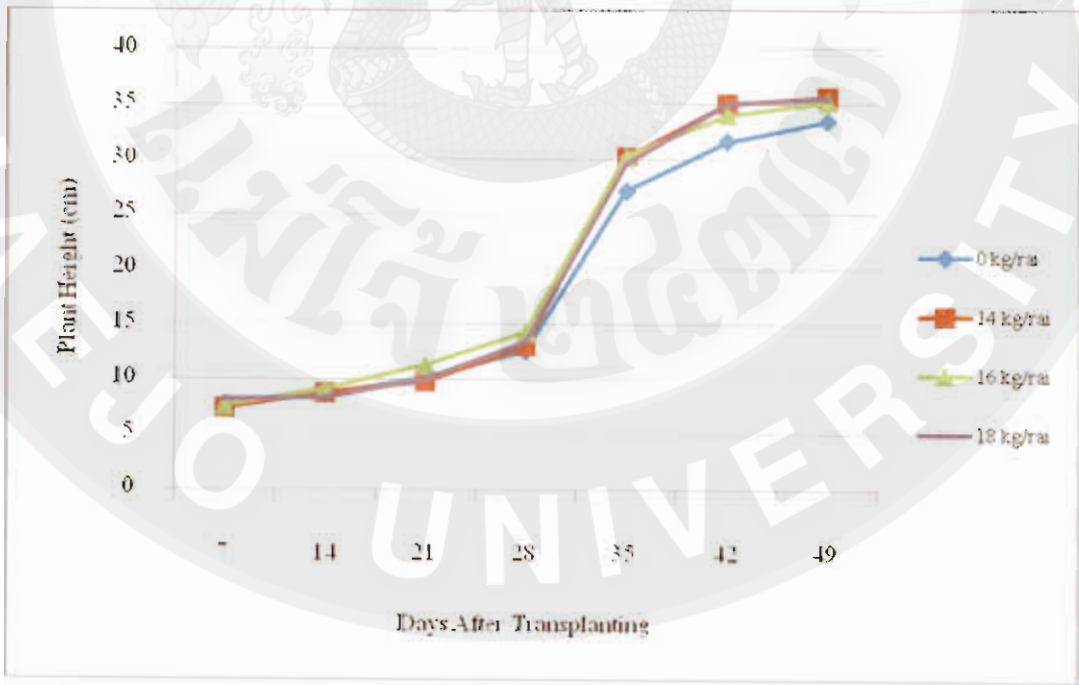


Figure 12 Effects of nitrogen on weekly plant height of cabbage.

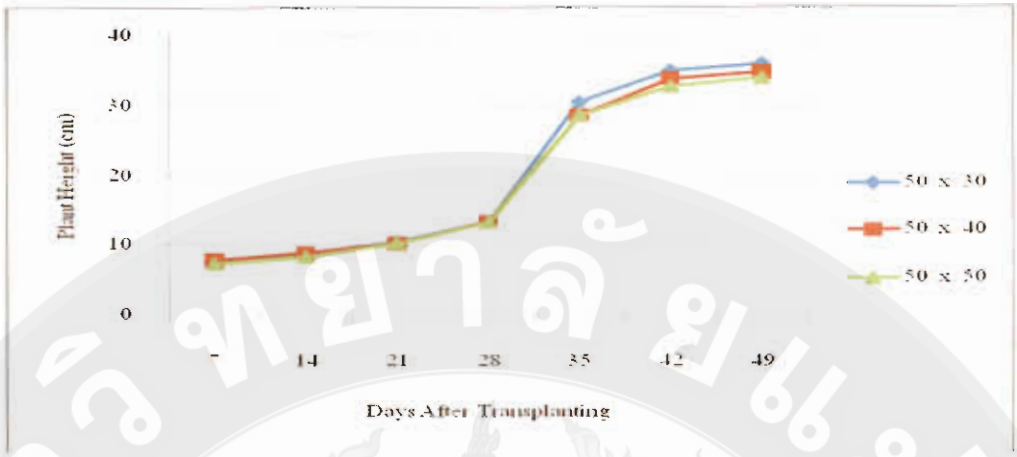


Figure 13 Effects of plant spacing on the weekly plant height of cabbage

Table 6 Effects of nitrogen and plant spacings on weekly plant height of cabbage

	Plant Height (cm)						
Treatments	**7 DAT**	**14 DAT**	**21 DAT**	**28 DAT**	**35 DAT**	**42 DAT**	**49 DAT**
Nitrogen (A)							
0 kg/rai	7.68	8.57	10.18 ab	12.6 b	27.07 b	31.58 b	33.39 b
14 kg/rai	7.29	8.68	9.78 b	12.96 ab	30.13 a	34.95 a	35.57 a
16 kg/rai	7.54	9.04	11.27 a	14.32 a	30.21 a	33.99 ab	35.14 a
18 kg/rai	8.2	8.35	10.07 ab	13.4 ab	29.53 a	34.94 a	35.44 a
F test	ns	ns	*	*	*	*	**
LSD	-	-	1.44	1.54	2.31	3.21	1.61
CV (%)	12.68	13.95	8.79	17.32	5.79	6.90	3.28
Plant Spacings (B)							
50 x 30 cm	7.89	8.87	10.51	13.37	30.52	35.04	35.99 a
50 x 40 cm	7.78	8.8	10.15	13.31	28.59	33.86	34.75 ab
50 x 50 cm	7.37	8.33	10.32	13.29	28.59	32.69	33.92 b
F test	ns	ns	ns	ns	ns	ns	**
LSD	-	-	-	-	-	-	1.40
CV (%)	8.56	7.68	10.14	8.40	7.92	6.90	4.64
A x B	ns	ns	ns	ns	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the Least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P> 0.05.

Leaf Length

The elongation of cabbage leaves as affected by different levels of nitrogen and plant spacing measured on a weekly basis are represented by figures 13, 14 and Table 7. There was no significant different at $P < 0.05$ in the length of the leaves as affected by nitrogen from 7 to 21 DAT. However, highly significant differences at $P < 0.01$ were observed in the length of the leaves among the treatments with different levels of nitrogen. The treatment with 18 kg N per rai recorded the longest leaf length of 20.74 cm while the control plots recorded the shortest leaf length of 18.48 cm at 28 DAT. Treatments with 18 kg N per rai were not statistically different from 16 kg N per rai but was however highly significantly different from 14 kg N per rai and the control plot. The length of leaves measured on weekly basis for the cabbage plants as affected by different levels of nitrogen was highly significantly different at $P < 0.01$ from 35 to 49 DAT. The plots applied with nitrogen were not significantly different among each other but they were however highly significantly different from the control plot. The plot applied with 18 kg N per rai recorded the longest leaf length of 34.50 cm while the control plot recorded the shortest leaf length of 31.20 cm on 49 DAT.

The length of leaf as affected by the different plant spacings was not significantly different from 7 to 21 DAT. It was significantly different at $P < 0.05$ on 28 DAT. The wider spacing of 50 cm between rows x 50 cm within rows recorded the longest leaf length of 20.65 cm while the closer spacing of 50 cm between rows x 30 cm within rows recorded the shortest leaf length of 19.47 cm on 28 DAT. There were no statistical difference between 50 cm x 30 cm and 50 cm x 40 cm. The leaf length recorded on 35 DAT was not statistical different among each other. However, significant differences were recorded among the treatments on 42 DAT. The plot with lowest plant density (50 cm x 50 cm) once again recorded the longest leaf length of 31.73 cm while the plot with highest plant density (50 cm x 30 cm) recorded the shortest leaf length of 30.42 cm. The control plot was however not significantly different from the treatment with 50 cm x 40 cm which was also not significantly different from the treatment with 50 cm x 50 cm. No statistical differences were recorded in the length of leaves between the different treatments on 49 DAT. No significant interaction was observed between the rates of nitrogen and different plant spacing in the measured leaf length of cabbage plants.

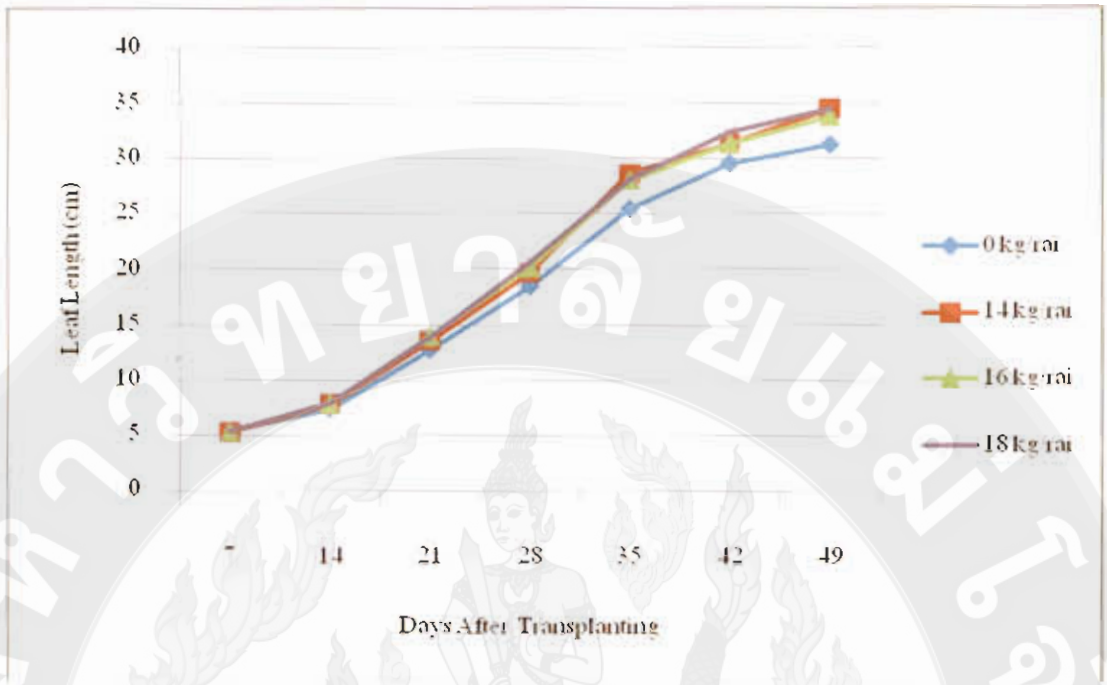


Figure 14 Effects of nitrogen on weekly leaf length of cabbage

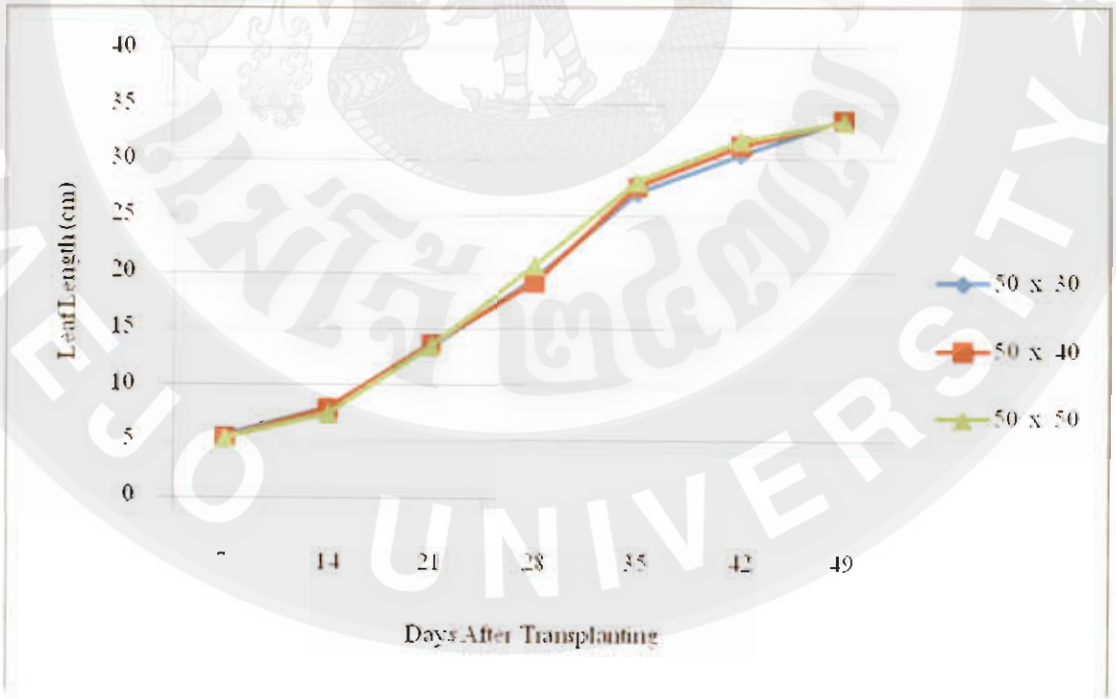


Figure 15 Effects of plant spacing on weekly leaf length of cabbage

Table 7 Effects of nitrogen and plant spacings on weekly leaf length for cabbage

	Leaf Length (cm)						
Treatments	**7 DAT**	**14 DAT**	**21 DAT**	**28 DAT**	**35 DAT**	**42 DAT**	**49 DAT**
Nitrogen (A)							
0 kg/rai	5.46	7.45	12.75	18.48 c	25.42 b	29.52 b	31.20 b
14 kg/rai	5.23	7.83	13.51	19.68 b	28.61 a	31.32 a	34.46 a
16 kg/rai	5.38	7.89	13.96	20.16 ba	28.03 a	31.35 a	33.78 a
18 kg/rai	5.42	7.96	13.84	20.74 a	28.16 a	32.41 a	34.50 a
F test	ns	ns	ns	**	**	**	**
LSD	-	-	-	0.83	1.49	1.19	1.50
CV (%)	10.86	15.37	9.62	4.38	7.85	3.78	2.91
Plant Spacings (B)							
50 x 30 cm	5.53	8.02	13.42	19.47 b	27.00	30.42 b	33.59
50 x 40 cm	5.30	7.90	13.70	19.13 b	27.62	31.30 ba	33.53
50 x 50 cm	5.29	7.42	13.42	20.65 a	28.04	31.73 a	33.34
F test	ns	ns	ns	*	ns	*	ns
LSD	-	-	-	0.72	-	1.03	-
CV (%)	8.81	8.76	9.62	4.19	5.40	3.83	4.47
A x B	ns	ns	ns	ns	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Leaf Width

Leaf width development of cabbage plants as affected by different levels of nitrogen and different plant spacing are represented in figure 15, 16 and Table 8. The width of leaves as measured until 21 DAT were not significantly different within the treatments. Highly significant difference at $P < 0.01$ was observed among the plots applied with nitrogen when compared with control plot from 28 DAT. Similar results were also observed at 35 DAT. Leaf width at 42 DAT was also highly significantly different with the plot having 18 kg N per rai recording the widest leaf of 34.77 cm and the control plot recording the narrowest leaf of 30.25 cm. Similar results were also observed on 49 DAT where the widest leaf (35.68 cm) was once

again recorded in the plot with 18 kg N per rai and the narrowest leaf (31.98 cm) was again recorded in the control plot.

Leaf width as affected by different plant spacings was significantly different at P < 0.05 at 28 DAT whereby the wider plant spacing of 50 cm between rows x 50 cm within rows recorded wider leaves (21.56 cm) which was statistically different from the plant spacing of 50 cm between rows x 40 cm within rows and 50 cm between rows x 30 cm within rows with the latter recording the narrowest leaf of 20. 73 cm. Highly significant different at P < 0.01 was also recorded in the leaf width from 35 to 49 DAT. The leaf width at 35 DAT was significantly different from each other where the widest leaf (30.43) was recorded in the plot with the widest plant spacing of 50 cm between rows x 50 cm within rows while the narrowest leaf (27.32 cm) was recorded in the plot with closer spacing of 50 cm between rows x 30 cm within rows. Similar observations were also made on 42 DAT. Width of leaves was significantly different at P < 0.01 at 49 DAT. However, there was no significant difference among the plant spacing of 50 cm x 30 cm and 50 cm x 40 cm. The interaction between the rates of nitrogen and different plant spacing was not significantly different in the measured width of cabbage leaves.

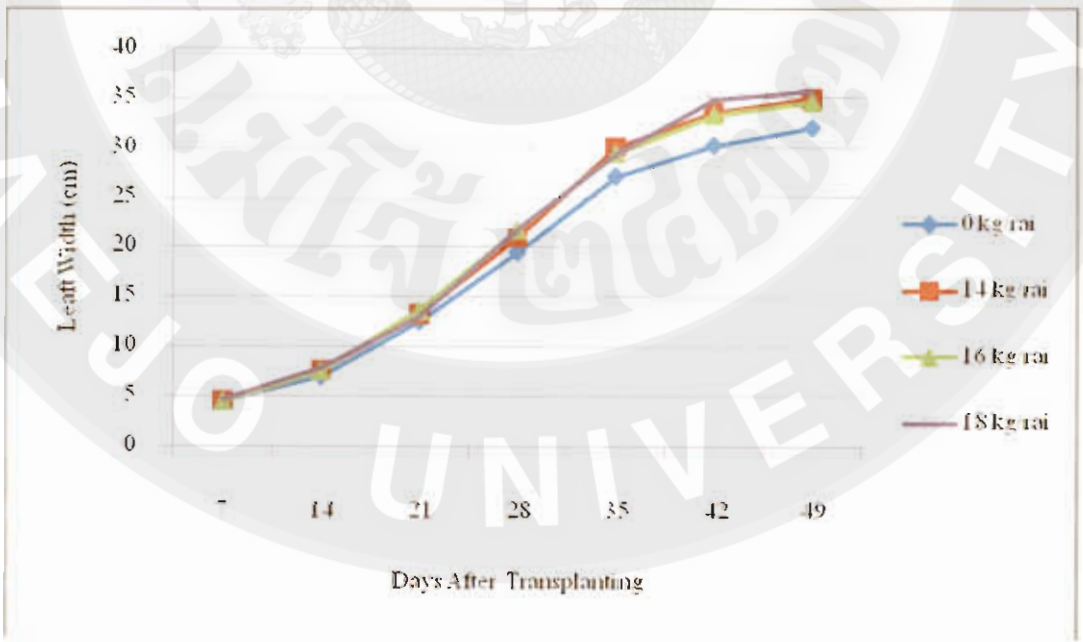


Figure 16 Effects of nitrogen on weekly leaf width of cabbage

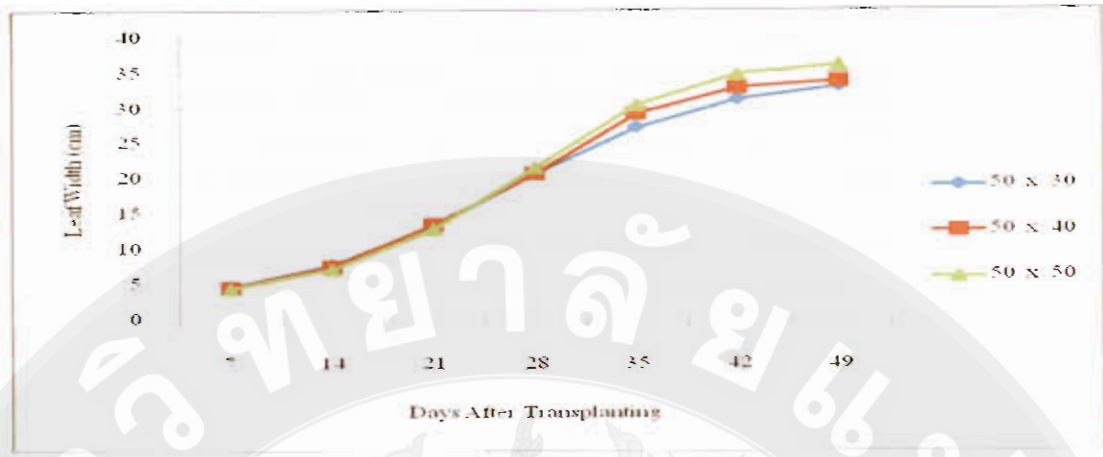


Figure 17 Effects of plant spacing on the leaf width of cabbage

Table 8 Effects of nitrogen and plant spacings on weekly leaf width of cabbage

	Leaf width (cm)						
Treatments	**7 DAT**	**14 DAT**	**21 DAT**	**28 DAT**	**35 DAT**	**42 DAT**	**49 DAT**
Nitrogen (A)							
0 kg/rai	4.53	7.03	12.56	19.53 b	27.11 b	30.23 c	31.98 c
14 kg/rai	4.56	7.64	13.35	20.97 a	30.09 a	33.55 ba	34.93 ba
16 kg/rai	4.52	7.60	13.7	21.73 a	29.39 a	33.25 b	34.49 b
18 kg/rai	4.66	7.84	12.98	21.81 a	29.39 a	34.77 a	35.68 a
F test	ns	ns	ns	**	**	**	**
LSD	-	-	-	0.89	1.30	1.27	1.00
CV (%)	10.94	14.91	8.40	5.17	5.41	2.86	2.86
Plant Spacings (B)							
50 x 30 cm	4.7	7.82	13.19	20.73 b	27.32 c	31.28 c	33.05 b
50 x 40 cm	4.56	7.61	13.44	20.71 b	29.23 b	32.89 b	33.79 b
50 x 50 cm	4.43	7.16	12.82	21.56 a	30.43 a	34.68 a	35.98 a
F test	ns	ns	ns	*	**	**	**
LSD	-	-	-	0.77	1.12	1.10	0.86
CV %	11.14	11.98	13.23	4.25	4.47	3.86	2.91
A x B	ns	ns	ns	ns	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Leaf Area

The leaf area was calculated by multiplying the length with the width of the leaf for the treatments as affected by different levels of nitrogen and plant spacings. The results are presented in figure 17, 18 and Table 9. No statistical differences were observed in the leaf area as affected by nitrogen and plant spacing from 7 to 21 DAT. However, highly significant differences were observed in the leaf area as affected by different rates of nitrogen from 28 to 49 DAT. The largest leaf area (425.77 cm^2) measured on 28 DAT was in the plots of 18 kg nitrogen per rai while the smallest (362.42 cm^2) was measured in the control plots. Treatments with 14 kg and 16 kg N per rai were not significantly different from each other but however, they were highly significantly different from the control. The treatments with 16 kg N per rai was not significantly different from the treatments with 18 kg N per rai but treatment with 14 kg N per rai was however highly significantly different. The observations on 35 DAT showed that the treatments with nitrogen (14, 16 and 18 kg per rai) were all highly significantly different at $P < 0.01$ from the control. Recordings on 42 DAT showed that treatments with 18 kg N per rai were highly significantly different from the treatments with 14 and 16 kg N per rai and the control plot. The treatments with 14 and 16 kg N per rai were not statistically different from each other but were however different from the control. The largest leaf area of 1231.39 cm^2 were recorded in the plots with the highest rate of nitrogen (18 kg per rai) while the smallest leaf area of 998.45 cm^2 was recorded in the control plot at 49 DAT. The treatments with nitrogen application were once again highly significantly different from the control plot.

The leaf area as affected by the different plant spacings was not significantly different from each other from 7 to 21 DAT. Significant difference at $P < 0.05$ was observed at 28 DAT where the largest leaf area of 445.92 cm^2 was recorded in the plot with plant spacing of 50 cm between rows x 50 cm within rows while the smallest was recorded in the plot of plant spacing of 50 cm between rows x 30 cm within rows. Recordings on 35 DAT showed highly significant difference among the treatments. The closest plant spacing (50 cm x 30 cm) had the smallest leaf area (739.38 cm cm^2) while the widest spacing (50 cm x 50 cm) had once again the largest leaf area of 855.05 cm^2. There were no significant difference between the plant spacings of 50 cm x 40 cm and 50 cm x 50 cm at 35 DAT. They were however highly significantly different from the plant spacing of 50 cm x 30 cm. On 42 DAT, the leaf area was once again highly

significantly different among each other. The recordings of 49 DAT showed the largest leaf area of 1208. 38 cm^2 was once again recorded in the plant spacing of 50 cm x 50 cm while the smallest leaf area of 1111.99 cm^2 was recorded in the plot with plant spacing of 50 cm x 30 cm. There were no statistical difference among the plant spacings of 50 cm x 50 cm and 50 cm x 40 cm. They were however, highly significantly different from the plant spacing of 50 cm x 30 cm. There was no significant interaction in the leaf area between the rates of nitrogen and different plant spacings.

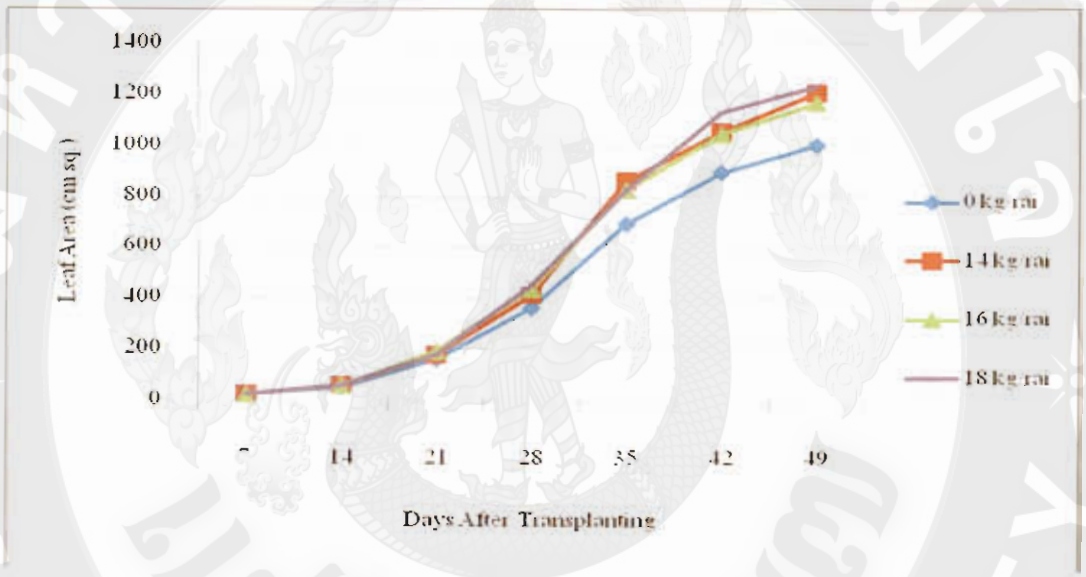


Figure 18 Effects nitrogen on the weekly measured leaf area of cabbage.

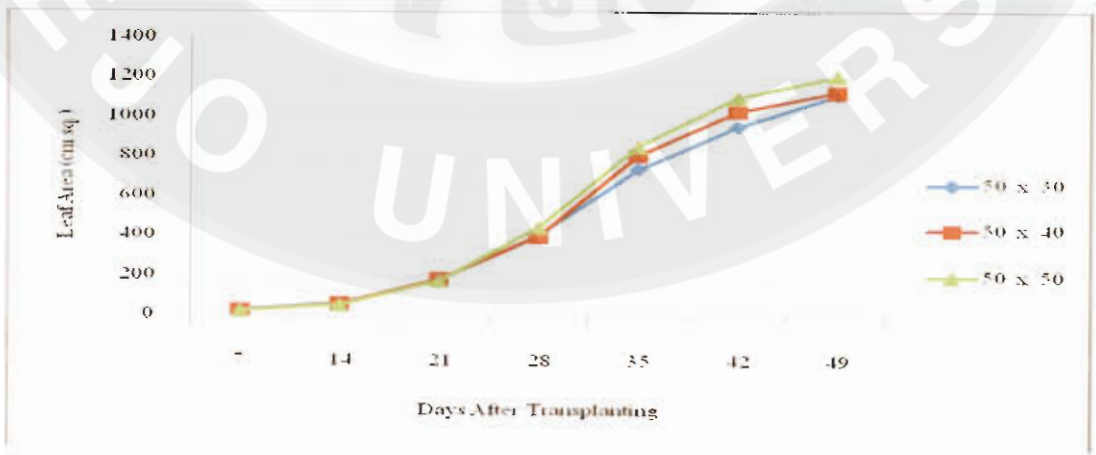


Figure 19 Effects of plant spacing on leaf area of cabbage plants.

Table 9 Effect of nitrogen and plant spacings on the weekly leaf area of cabbage plants.

Treatments	Leaf Area (cm^2)						
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT
Nitrogen (A)							
0 kg/rai	24.91	53.41	163.27	362.42 c	691.09 b	893.49 c	998.45 b
14 kg/rai	24.07	60.19	181.45	413.62 b	861.68 a	1051.86 b	1203.99 a
16 kg/rai	24.47	60.89	194.14	438.95 ba	825.13 a	1044.34 b	1165.08 a
18 kg/rai	25.54	62.96	181.52	452.77 a	827.84 a	1127.54 a	1231.39 a
F test	ns	ns	ns	**	**	**	**
LSD	-	-	-	30.01	61.68	68.01	71.42
CV (%)	20.81	28.88	16.13	7.71	11.27	5.13	4.69
Plant Spacings (B)							
50 x 30 cm	26.11	63.17	178.92	405.72 b	739.38 b	954.31 c	1111.99 b
50 x 40 cm	24.21	61.37	186.16	399.18 b	809.88 a	1030.89 b	1128.81 b
50 x 50 cm	23.92	53.54	175.21	445.92 a	855.05 a	1102.71 a	1208.38 a
F test	ns	ns	ns	*	**	**	**
LSD	-	-	-	25.99	53.41	58.90	61.86
CV %	19.24	19.71	20.98	7.20	7.70	6.61	6.22
A x B	ns	ns	ns	ns	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Yield components

Stem diameter

The stem diameter as measured at harvest of the cabbage heads are represented in Table 10. There was highly significantly difference at $P < 0.01$ in the stem diameter as affected by different rates of nitrogen applied in the plots when compared to the control plot. The highest stem diameter (20.25 mm) was recorded in the plot that was applied with 18 kg N per rai while the lowest (18.37 mm) was recorded in the control plot.

Different plant spacings also had positive effects on the stem diameter. Highly significant difference at $P < 0.01$ was observed in the stem diameter for different plant spacings.

The highest (20.54 mm) was recorded in the plant spacing of 50 cm between rows x 50 cm within rows while the lowest (18.84 mm) was recorded in the plant spacing of 50 cm between rows x 30 cm within rows. No significant interaction was observed in the stem diameter between the rates of nitrogen and different plant spacings.

Number of wrapper leaves

The average numbers of wrapper leaves recorded per head are tabulated in table 10. There were no significant differences recorded in the number of wrapper leaves among each treatment as affected by different rates of nitrogen or different plant spacing.

Number of frame leaves

Observations for the number of frame leaves recorded per plant in the experiment are also given in table 10. No significant difference at $P < 0.05$ was observed in the number of frame leaves in the treatments with different rates of nitrogen. Significant difference at $P < 0.05$ was however observed in the treatments with different plant spacings. The highest number of frame leaves (15.95) was recorded in the widest plant spacing of 50 cm x 50 cm while the lowest (14.77) was recorded in the plant spacing of 50 cm x 30 cm. There were no significant difference in the number of frame leaves between the plant spacing of 50 cm x 30 cm and the plant spacing of 50 cm x 40 cm and the latter with 50 cm x 50 cm. Significant difference were however noted among the plant spacing of 50 cm x 50 cm with the plant spacing of 50 cm x 30 cm.

No significant interaction was observed in the number of wrapper and frame leaves between the rates of nitrogen and different plant spacings in the experiment.

Table 10 Effects of nitrogen and plant spacings of stem diameter, number of wrapper leaves and Number of frame leaves of cabbage

Treatments	Stem diameter per plant (mm)	No. of wrapper leaves per head	No. of frame leaves per plant
Nitrogen (A)			
0 kg/rai	18.37 b	34.91	15.36
14 kg/rai	19.92 a	37.28	15.20
16 kg/rai	19.95 a	36.78	15.20
18 kg/rai	20.25 a	37.44	15.62
F test	**	ns	ns
LSD	0.63	-	-
CV (%)	2.89	5.78	6.22
Plant Spacings (B)			
50 x 30 cm	18.84 c	36.14	14.77 b
50 x 40 cm	19.49 b	36.75	15.35 ba
50 x 50 cm	20.54 a	36.92	15.92 a
F test	**	ns	*
LSD	0.55	-	0.77
CV (%)	3.23	8.13	5.83
A x B	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Cabbage plants with different plant spacing in the field

Figure 20 Plant spacing of 50 cm between row x 30 cm within rows (6.67 plants/m^2)

Figure 21 Plant spacing of 50 cm between row x 40 cm within rows (5 plants/m^2)

Figure 22 Plant spacing of 50 cm between row x 50 cm within rows (4 plants/m^2)

Yields

Plant biological yield

The biological yield from the experiment is represented in Table 11. The results indicate highly significant difference at $P < 0.01$ among the different treatments within the experiment. The highest biological weight per plant (2.28 kg) as influenced by the rates of nitrogen was recorded in the plot with 18 kg N per rai. This was followed by the plot with 16 kg N per rai with average of 2.07 kg per plant. Plot with 14 kg N per rai recorded the third highest weight of 1.91 kg per plant while the lowest (1.68 kg) was recorded in the control plot. The plot with 18 kg N was highly significantly different from the plot with 14 kg N per rai and the control

while it was not statistically different from the plots with 16 kg N per rai. Plot with 14 kg N were not significantly different at $P < 0.05$ from the plot with 16 kg N per rai. Different rates of nitrogen also had positive effects on the biological weight of cabbage per m^2. The highest weight per m^2 (11.83 kg/ m^2) was obtained in the plot with 18 kg N per rai followed by plot with 16 kg N producing 10.99 kg/m^2 while plot with 14 kg N yield 9.99 km/m^2. The lowest biological weight of 8.76 kg/m^2 per plant was recorded in the control plot. Plot with 18 kg N was highly significantly different from the plot with 14 kg N and the control plot; however, it was not significantly different from the plot with 16 kg N per rai. There was no significant difference at $P < 0.05$ level among the control and the plot with 14 kg N per rai.

Cabbages planted at different spacings also recorded highly significant difference between the treatments. The highest biological weight per plant (2.25 kg) was recorded in the plant spacing of 50 cm between rows x 50 cm within rows followed by plot with the plant spacing of 50 cm between rows x 40 cm within rows recording a weight of 1.91 kg and the lowest weight of 1.79 kg was recorded in the plot with plant spacing of 50 cm between rows x 30 cm within rows. The plot with the plant spacing of 50 cm x 50 cm was highly significantly different from the plot having the plant spacing of 50 cm x 40 cm and 50 cm x 30 cm. However, the plant spacing of 50 cm x 30 cm was not statistically different from the plant spacing of 50 cm x 40 cm. Highly significant difference at $p < 0.01$ was also observed between the treatments with different plant spacing on the biological weight per m^2. Plot with the plant spacing of 50 cm x 30 cm were highly significant from the plots with the spacing of 50 cm x 40 cm and 50 cm x 50 cm. There were no significant difference among the plots with plant spacing of 50 cm x 40 cm and 50 cm x 50 cm. The highest weight of 12.20 kg per m^2 was obtained in the plot with the plant spacing of 50 cm x 30 cm having a plant density of 66,667 plants per ha. This was followed by a recording of 9.94 kg per m^2 in the plots having the spacing of 50 cm x 40 cm with a plant density of 50,000 plants per ha. The lowest biological weight was recorded in the plot with plant spacing of 50 cm x 50 cm with a plant density of 40,000 plants per ha.

No significant interaction was observed in the biological yield between the rates of nitrogen and different plant spacing; suggesting that these variables are independent of each other in giving a positive response to the measured characteristics.

Table 11 Effects of nitrogen rates and plant spacings on biological yield of cabbage

Treatments	Biological weight per plant (kg)	Biological weight per m^2	Biological yield (tons per ha)
Nitrogen (A)			
0 kg/rai	1.68 c	8.76 c	87.58 c
14 kg/rai	1.91 bc	9.99 bc	99.86 bc
16 kg/rai	2.07 ba	10.96 ba	109.56 ba
18 kg/rai	2.28 a	11.83 a	118.26 a
F test	**	**	**
LSD	0.24	1.37	13.72
CV (%)	16.67	18.02	18.03
Plant Spacings (B)			
50 x 30 cm	1.79 b	12.20 a	122.00 a
50 x 40 cm	1.91 b	9.94 b	99.41 b
50 x 50 cm	2.25 a	9.00 b	90.03 b
F test	**	**	**
LSD	0.20	1.19	11.88
CV (%)	11.84	13.22	13.22
A x B	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Biological yield per hectare

The biological yield per ha in the plots as affected by different levels of nitrogen was highly significantly different at $P < 0.01$ as presented in Table 11. Plot receiving 18 kg N per rai (112.5 kg/ha) was highly significantly different from the plots with 14 kg N per rai (87.5 kg/ha) and the control. It was however not significantly different from the plot having 16 kg N per rai (100 kg/ha) which was not significantly different from the plot with 14 kg N per rai but was highly significantly different from the control. The highest biological yield per ha (118.26

tons/ha) was recorded in the plot with 18 kg N per rai followed by plot with 16 kg N per rai (109.56 tons/ha) then plots with 14 kg N per rai (99.86 tons/ha). The lowest yield (87.58 tons/ha) was recorded in the control plot.

Highly significant difference was also observed in the treatments with different plant spacings. Treatments with the plant spacing of 50 cm between rows x 50 cm within rows (40,000 plants/ha) were not significantly different from the spacing of 50 cm between rows x 40 cm within rows (50,000 plants/ha) but they were highly significantly different from the spacing of 50 cm between rows x 30 cm within rows (66,667 plants/ha). The highest biological yield (122. 00 tons/ha) was recorded in the plot with spacing of 50 cm x 30 cm followed by plant spacing of 50 cm x 40 cm (94.41 tons/ha) and the lowest yield of 90.03 tons/ha was recorded in the spacing of 50 cm x 50 cm.

Economical yield

The economical or marketable weights are tabulated in Table 12. Highly significant difference was observed in the economical weight per head of cabbage among the different levels of nitrogen. Plot receiving 18 kg N per rai were highly significantly different from the plots applied with 14 kg N per rai and the control. It was however, not significantly different from the plot with 16 kg N per rai. The largest head size (1.13 kg per head) was recorded in the treatments with 18 kg N followed by 16 kg (1.04 kg per head) and then 14 kg (0.99 kg per head) N per rai. The control plot recorded the lowest head weight of 0.76 kg per head. The economical weight per m^2 was also highly significantly different among the treatments. Plots applied with nitrogen were highly significantly different from the control but they were not statistically different among each other. Nevertheless, the highest weight per m^2 of 6.28 kg was obtained in the plot with 18 kg N while the lowest weight of 4.24 kg/m^2 was recorded in the control plot.

The weight per head was also highly significantly different among the treatments of different plant spacing. The plant spacing of 50 cm between rows x 50 cm within rows recorded the highest weight per head (1.17 kg) and was highly significantly different from the plant spacings of 50 cm between rows x 40 cm within rows and 50 cm between rows x 30 cm within rows. The second highest weight per head (0.96 kg) was recorded in the plot with the plant spacing of 50 cm x 40 cm while the plot with the spacing of 50 cm x 30 cm recorded the lowest

(0.81 kg) economical weight per head. The interaction between the rates of nitrogen and different plant spacings for the economic yield was not significantly different.

Table 12 Effects of nitrogen rates and plant spacings on economical yield of cabbage

Treatments	Economical weight per head (kg)	Economical weight per m^2	Economical yield (tons per ha)
Nitrogen (A)			
0 kg/rai	0.76 c	4.24 b	42.36 b
14 kg/rai	0.99 b	5. 37 a	53.72 a
16 kg/rai	1.04 ba	5.48 a	54.82 a
18 kg/rai	1.13 a	6.28 a	62.79 a
F test	**	**	**
LSD	0.11	0.96	9.57
CV (%)	22.82	24.77	24.79
Plant Spacings (B)			
50 x 30 cm	0.81 c	6.36 a	63.64 a
50 x 40 cm	0.96 b	5.04 b	50.44 b
50 x 50 cm	1.17 a	4.62 b	46.19 b
F test	**	**	**
LSD	0.10	0.83	8.28
CV (%)	11.65	17.92	17.12
A x B	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Economic yield per hectare

The economic yield per ha was highly significantly different between the plots applied with nitrogen when compared with the control. There was no significant difference between the different levels of nitrogen applied. However, the highest yield (62.79 tons per ha) was obtained in the plot with 18 kg N per rai followed by 16 and then 14 kg N per rai which yielded 54.82 and 53.72 tons per ha respectively. The lowest yield (42.36 tons per ha) was recorded in the control plot.

Highly significant difference at $P < 0.01$ was also observed in the plot as controlled by different plant spacings. While the plant spacings of 50 cm between rows x 50 cm within rows and 50 cm between rows x 40 cm within rows was not significantly different from each other, they were however highly significantly different from the plant spacing of 50 cm between rows x 30 cm within rows. The highest yield (63.64 tons per ha) was obtained in the treatments with the plant spacing of 50 cm x 30 cm (66,667 plants per ha) followed by 50 .44 tons per ha from the spacing of 50 cm x 40 cm (50,000 plants per ha), while the spacing of 50 cm x 50 cm (40,000 plants per ha) recorded the lowest yields of 46.19 tons per ha.

Figure 23 Cabbage head with 0 kg N per rai with three different plant spacings

Figure 24 Cabbage head with 14 kg N per rai with three different plant spacings

Figure 25 Cabbage head with 16 kg N per rai with three different plant spacings

Figure 26 Cabbage head with 18 kg N per rai with three different plant spacings

Figure 27 Cabbage heads from different treatments in the experiment

Quality characteristics of cabbage

Head firmness

Head firmness or compactness is an important characteristic for the determination of the quality of cabbage. Head firmness in the experiment as observed in the treatments with different levels of nitrogen was highly significantly different at $P < 0.01$ as presented in Table 13. The plots with 18 kg and 16 kg N per rai were not significantly different from each other but they were however highly significantly different from the plot with 14 kg N per rai and the control. The most compact heads (6.19 kg/cm^2) were recorded in the plot with 18 kg N followed by plot with 16 kg N (5.84 kg/cm^2) and then in the plot with 14 kg N per rai (5.31 kg/cm^2). The control plot recorded head compaction of 5.35 kg/cm^2 which was not statistically different from the plot with 14 kg N per rai.

There was no significant difference observed in the head firmness as influenced by different plant spacings. However, the plot with plant spacing of 50 cm within rows x 30 cm within rows recorded the most compact heads (5.76 kg/cm^2) followed by the treatments with plant spacings of 50 cm x 50 cm (5.71 kg/ cm^2) and 50 cm x 40 cm (5.54 kg/cm^2).

No significant interaction was observed for head firmness between the rates of nitrogen and different plant spacing.

Head height

The results for the height of cabbage heads as measured in the experiment are given in Table 13. The results show that nitrogen has a positive effect on the height of cabbage heads. Highly significant difference at $P < 0.01$ level were recorded in the head height among different treatments. Plots applied with nitrogen were highly significantly different from the control. Treatments with 14 kg N per rai was not significantly different from the plot with 16 kg N but was however highly significantly different from the plot with 18 kg N per rai. The highest head height (13 .02 cm) was recorded in the plot with 18 kg N followed by a recording of 12.43 cm in the plot with 16 kg N then 11.91 cm in the plot with 14 kg N. The lowest head height (10.52 cm) was recorded in the control plot.

Head height as influenced by different plant spacings was also highly significantly different at $P < 0.01$ when the plot with the plant spacing of 50 cm between rows x 50 cm within rows recorded the highest head height (13.02 cm) which was highly significantly different from the plant spacings of 50 cm between rows x 40 cm within rows and 50 cm between rows x 30 cm within rows. All the treatments were highly significantly different from each other where the second highest head height (11.82 cm) was recorded in the plant spacing of 50 cm x 40 cm while the lowest head height (11.14) was recorded in the plant spacing of 50 cm x 30 cm.

There was no significant interaction in the head height between the rates of nitrogen and the different plant spacing.

Head width

The effect of nitrogen and plant spacing of the head width of cabbage are given in Table 13. The results show that there was highly significant different among the different levels of nitrogen on the width of cabbage heads. The plot with 18 kg N per rai were not statistically different from the plot with 16 kg N but were however highly significantly different from the plot with 14 kg N and the control plot. Plot with 16 kg N per rai were also not significantly different at $P < 0.05$ from the plot with 14 kg N but both were however highly significantly different from the control. The highest head width of 16.33 cm was recorded in the plot with 18 kg N per rai followed by a recording of 15. 42 cm in the plot applied with 16 kg N per rai. Plot with 14 kg N per rai recorded the third highest head width of 14.82 cm while the control plot recorded the lowest head width of 13.66 cm.

Highly significant differences were also observed among different plant spacing within the experiment. Plant spacing of 50 cm x 50 cm was highly significantly different from the control plot but it was however not significantly different from the spacing of 50 cm x 40 cm which was also highly significantly different from the control. The head height (15.97 cm) was recorded in the spacing of 50 cm x 50 cm followed by the spacing of 50 cm x 40 cm (15.33 cm) while the lowest (13.86 cm) was recorded in the plot with the plant spacing of 50 cm x 30 cm.

No significant interaction could be observed in the head width between the levels of nitrogen and different plant spacing arraignments.

Table 13 Effects of nitrogen and plant spacings on firmness, height and width of cabbage heads

Treatments	Head firmness (kg/cm^2)	Head height (cm)	Head width (cm)	Unmarketable yield (%)
Nitrogen (A)				
0 kg/rai	5.35 b	10.52 c	13.66 c	70.58 a
14 kg/rai	5.31 b	11.91 b	14.82 b	63.03 ba
16 kg/rai	5.84 a	12.43 ba	15.42 ba	55.57 b
18 kg/rai	6.19 a	13.12 a	16.33 a	40.37 c
F test	**	**	**	**
LSD	0.48	0.69	0.94	12.46
CV (%)	10.28	3.23	12.09	31.95
Plant Spacings (B)				
50 x 30 cm	5.76	11.14 c	13.86 b	76.15 a
50 x 40 cm	5.54	11.82 b	15.33 a	59.35 b
50 x 50 cm	5.71	13.02 a	15.97 a	36.66 b
F test	ns	**	**	**
LSD	-	0.60	0.82	10.79
CV %	8.45	5.78	6.27	21.73
A x B	ns	ns	ns	ns

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Unmarketable yield

The percentage of unmarketable yield was highly significantly different in both the different rates of nitrogen and plant spacings. The highest unmarketable yield was from the control plot (70.58%) and the plant spacing of 50 x 30 cm (76.15%). The plot with 18 kg N per rai recorded the lowest unmarketable yield (40.37 %) and was highly significantly different from the plots with 16 kg, 14 kg N per rai and the control. Wider plant spacing of 50 x 50 cm also recorded the lowest unmarketable yield (36.66%) however, it was not significantly different from the plant spacing of 50 x 40 cm but was highly significantly different from the spacing of 50 x 30 cm.

Dry matter content of cabbage head

The dry matter content among different rates of nitrogen was significantly different at $P < 0.05$ as presented in table14. Plot with 18 kg N per rai were not significantly different from the plot with 16 kg N per rai, it was however significantly different from the treatment with 14 kg N per rai and the control plot. The treatments with 16 kg, 14 kg and the control were not significantly different among each other. The highest dry matter content was recorded in the control plot (8.29%) followed by plot with 14 kg N per rai (8.13%) and plot with 16 kg N per rai (8.04%). The lowest (7.56%) was recorded in the plot with 18 kg N per rai.

No significant differences were observed in the dry matter content at different plant spacing. However, the highest dry matter content (6.36%) was observed in the plot with the plant spacing of 50 cm between rows x 30 cm within rows followed by the plant spacing of 50 cm between rows x 40 cm within rows (5.04%) while the lowest (4.62%) was recorded in the plant spacing of 50 cm between rows x 50 cm within rows.

The dry matter content did not show any significant interaction between the different levels of nitrogen and the different plant spacing.

Total soluble solid content

The results from the total soluble solid are represented in table 14. No significant differences at $P < 0.05$ were observed in the total soluble solid measured between the different rates of nitrogen. The highest TSS (4.16 degree brix) was however recorded in the plot with 18 kg N while plots with 16 kg and 14 kg N per rai recorded a TSS of 3.90 degree brix. The lowest (3.68 degree brix) was recorded in the control plot.

No significant differences at $P < 0.05$ were also observed in the total soluble solid content in cabbage heads between the different plant spacing. Highest TSS of 3.96 degree brix was recorded in the plot with plant spacing of 50 cm between rows x 40 cm within rows followed by a recording of 3.90 degree brix in the plant spacing of 50 cm between rows x 50 cm within rows while the lowest TSS of 3.87 degree brix was recorded in the plant spacing of 50 cm between rows x 30 cm within rows.

No significant difference was also observed in the interaction between the different levels of nitrogen and different plant spacing in this experiment.

Table 14 Effects of nitrogen and plant spacings on dry matter and total soluble solid and nitrate content of cabbage heads

Treatments	Dry matter content (%)	Total soluble solid content (Degree Brix)	Nitrate Content (mg/kg)
Nitrogen (A)			
0 kg/rai	8.29 a	3.68	171.01 d
14 kg/rai	8.13 a	3.90	476.32 c
16 kg/rai	8.04 ba	3.90	687.91 b
18 kg/rai	7.56 b	4.16	964.91 a
F test	*	ns	**
LSD	0.55	-	39.45
CV (%)	6.61	17.53	8.06
Plant Spacings (B)			
50 x 30 cm	8.16	3.87	523.27 a
50 x 40 cm	7.94	3.96	566.33 b
50 x 50 cm	7.90	3.90	635.52 c
F test	ns	ns	**
LSD	-	-	34.14
CV %	6.97	10.44	6.86
A x B	ns	ns	**

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Food Safety

Nitrate content

The nitrate content observed among different treatments is presented in table 14. Highly significant differences were observed among different rates of nitrogen on the nitrate content of the heads. The highest nitrate content of 964.91 mg/kg was recorded in the plot with 18 kg N per rai followed by the recording of 687.91 mg/kg in the plot applied with 16 kg N per rai. The third highest nitrate content of 476.32 mg/kg was recorded in the plot with 14 kg N per rai while the lowest (171.01 mg/kg) was recorded in the control plot.

Different plant spacings also had a highly significant effect on the nitrate content. All three different plant spacings recorded highly significant difference between each other. The highest nitrate content (635.52 mg/kg) was recorded in the plot with the plant spacing of 50 cm between rows x 50 cm within rows followed by the plant spacing of 50 cm between rows x 40 cm within rows (566.33 mg/kg) while the lowest (523.27 mg/kg) was recorded in the plant spacing of 50 cm between rows x 30 cm within rows.

Highly significant difference was observed in the interaction between the rates of nitrogen and different plant spacing for the nitrate content in cabbage leaves.

Experiment 2 – Comparative study of pest control methods on yield, quality and food safety of cabbage

Yield

Plant biological weight

The results of the biological weight from the experiment are given in Table 15. Different pest control methods were not significantly different at $P < 0.01$ between each other; but they were highly significantly different from the control. The highest weight per plant (1.62 kg) was recorded in the plot used for IPM control followed by plot used by organic pest control (1.57 kg). The third highest biological weight (1.52 kg) was recorded in the plot used for chemical pest control while the control plot recorded the lowest (1.05 kg) biological weight per plant.

Biological yield per m^2 was also highly significantly different at $P < 0.01$. No statistical difference were observed among different pest control systems; but they were however highly significantly different from the control. The highest weight of 4.05kg/m^2 was recorded in the plot with IPM pest control system while the second highest yield of 3.93 kg/m^2 was recorded in the plot with organic pest control system sprayed with BT. Plot with chemical pest control system recorded the third highest yield of 3.79 kg/m^2 while the control recorded the lowest of 2.63 kg/m^2.

Table 15 Effects of pest control methods on biological yield of cabbage

Treatments	Biological weight (kg/plant)	Biological weight (kg/m^2)	Biological weight (tons/ha)
Pest control methods			
Control	1.05 b	2.63 b	26.25 b
Organic	1.57 a	3.93 a	39.73 a
Chemical	1.52 a	3.79 a	37.9 a
IPM	1.62 a	4.05 a	40.50 a
F test	**	**	**
LSD	0.27	0.67	6.75
CV %	11. 67	11.72	11.72

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Biological yield per ha

Highly significant difference was observed among the plot with pest control systems and the control as shown in Table 15. There was no significant difference within the different pest control systems. The highest biological yield of 40.50 tons/ha was obtained in the plot with IPM pest control system while the second highest yield of 39.23 tons/ha was recorded in the plot with organic pest control system. The plot with chemical pest eontrol system recorded a biological yield of 37.90 tons/ha whereas the lowest yield of 26.25 tons/ha were reeorded in the control plot.

Economical yield

Significant difference at $P < 0.05$ was observed among the different pest control systems and the control plot for the economical weight per head and also for the economical weight per m^2 as represented in Table 16. There was however no significant difference within the plots for different pest control systems. The highest economical weight (0.79 kg/head) was obtained from the plot of organic pest control followed by the plot with IPM control system (0.75

kg/head) and then by the plot with chemical pest control system (0.69 kg/head) while the lowest weight (0.44 kg/head) was recorded in the control plot.

The highest yield of 1.97 kg/m^2 was obtained in the treatments with organic pest control followed by the IPM control system (1.89 kg/m^2). The third highest was recorded in the plot with chemical control system (1.73 kg/m^2) while the control plot once again recorded the lowest (1.11 kg/ m^2) economical weight.

Table 16 Effects of pest control methods on economical yield of cabbage heads

Treatments	Economical weight (kg/head)	Economical weight (kg/m^2)	Economical weight (tons/ha)
Pest control methods			
Control	0.44 b	1.11 b	11.1 b
Organic	0.79 a	1.97 a	19.70 a
Chemical	0.69 a	1.73 a	17.30 a
IPM	0.75 a	1.89 a	18.85 a
F test	*	*	*
LSD	0.21	0.54	5.39
CV %	20.06	20.16	20.16

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Economic yield per ha

The results of the economic yield per ha is provided in Table 16. Highly significant difference was observed among the treated plots when compared to untreated plots. No significance at P < 0.05 was however found within the treated plots. The highest yield (19.65 tons/ha) was recorded in the treatment where BT (organic) was applied followed by (18.85 tons/ha) the plot with IPM pest control system. Third highest yield (17.3 tons/ha) was recorded in the plot sprayed with abamectin (Chemical control) while the control plot recorded the lowest (11.10 tons/ha) yield.

Pest damage assessment

Number of damage frame leaves

Highly significant difference $P < 0.01$ was observed among the treatments executed with pest control methods when compared with the control plot as presented in Table 17. The highest number (2.13 leaves) of frame leaves was damaged in the control plot followed by (0.30 leaves) the plot with organic control system. The plot with chemical control and IPM did not record any damaged frame leaves.

Number of damage wrapper leaves

The results from the number of damaged wrapper leaves are presented in Table 17. There was highly significant difference at $P < 0.01$ observed between the treatments applied with pest control methods when compared with the control plot. The highest number (3.63 leaves) of damaged wrapper leaves were recorded in the control plots where no pest control was undertaken. This was followed by the treatments with chemical control (0.81 leaves) then organic control system (0.45 leaves). The lowest number (0.31 leaves) of damaged wrapper leaves were recorded in the IPM plots.

Pest larvae count

The insect pest that were found in the cabbage were Diamond Back Moth (*Plutella xylotella*), Cabbage Lopper (*Trichoplusis ni*), White Butterfly (*Pieris rapae*) and Cluster Caterpillar (*Spodoptera litura*) are presented in Table 17. Highly significant difference was observed at $P < 0.01$ between the treatments applied with pest control when compared with the control plot. There was no significant difference between the different pest control systems. The highest pest count (46.25 larvae) was recorded in the control plot over the growth period of cabbage. This was followed by 3.50 larvae in the plot with IPM then 4.00 larvae in the organic control plot while the lowest (3.25 larvae) was recorded in the plot with chemical control.

Table 17 Effects of pest control methods on damages sustained in cabbage plant

Treatments	Number of damage frame leaves	Number of damage wrapper leaves	Pest larvae count
Pest control methods			
Control	2.16 a	3.63 a	46.25 a
Organic	0.30 b	0.45 b	4.00 b
Chemical	0.00 b	0.81 b	3.25 b
IPM	0.00 b	0.31 b	3.50 b
F test	**	**	**
LSD	1.23	0.54	19.89
CV %	126.72	54.75	87.24

Note: Figures represented by the same letter are not significantly different from each other at * ** P=0.05, 0.01 by the least Significant Difference (LSD). DAT = days after transplanting, ns = not significant at P > 0.05.

Food safety

Pesticide residue

The pesticide residue of the produce from the treatments of chemical control and IPM control was analyzed for abamectin residual content. The results are presented in appendix 1.0. There was no pesticide residue detected in the samples obtained from both the treatments. The results reported as "not detected".

Cost of cabbage production

The estimated cost of production calculated based on current market price are given in Table 18 and 19. Marketable yield that was suitable for export based on weight per head was separated from the unmarketable yield which was only suitable for the local market. Control plot with 0kg N per rai had an unmarketable yield of 70.58% (4,779.90 kg) and a marketable yield of 29.42% (2,000kg) while plot with 14 kg N per rai had an unmarketable yield of 63.03% (5,414.28 kg) and a marketable yield of 36.97% (3,175.72 kg). The plot with 16 kg N per rai recorded an unmarketable yield of 55.57% (4,873.49 kg) and marketable yield of 44.43%

(3,896.51 kg) while plot with 18 kg N per rai recorded an unmarketable yield of 40.37% (4,057.19) and marketable yield of 59.63% (5,992.82 kg).

The highest gross margin (50,504.15฿) was obtained from applying 18 kg of nitrogen per rai. This was 70.44% higher than the control plot, 42.11% higher than the plot with 14 kg nitrogen and 33.31% higher than the plot with 16 kg nitrogen per rai. The second highest gross margin (33,682.55฿) was obtained from using 16 kg nitrogen per rai which was 55.68% higher than the control plot and 13.19% higher than the plot with 14 kg nitrogen per rai. The treatment with 14 kg nitrogen had a gross margin of 29,238.60฿ and was 48.94% higher than the control plot while the lowest (14,929฿) was obtained from the control plot whcre no nitrogen was applied.

Table 18 Estimated agro-inputs and labour cost of production for cabbage

Expenses		
	Particulars	**Cost per rai (฿)**
Agro-inputs	Plastic mulch (16 rolls @ 980฿/roll)	15,680
	Seeds (50g)	100
	Phosphorus (14 kg/rai of 0-46-0)	840
	Potassium (72 kg/rai of 0-0-50)	1,080
	Potting media (5 bags)	2000
	Insecticide Abamectin (120 ml)	160
	BT (320 ml)	250
	Nematode (75 gram)	300
	Sticking traps	360
Labour	Bed preparation (15 mandays)	3,000
	Transplanting (12 mandays)	2,400
	Weeding (5 mandays)	1,000
	Spraying (4 mandays)	600
	Fertilizing (1 manday)	200
	Harvesting (6 mandays)	1,200
Total Cost		**29,170**

Table 19 Cost of production for cabbage with different rates of nitrogen per rai.

Agro-input & labour cost (฿)	Cost (฿) at different rates of nitrogen	Total cost (฿)	Total Yield (tons/rai)	Yield export market (kg)	Yield local market (kg)	Income export market 10 ฿/kg	Income local market 5 ฿/kg	Gross margin per rai (฿)
29,170	0 kg/rai	28,970	6.78	2,000	4,779.9	20,000	23,899.5	14,929.50
29,170	14 kg/rai (420฿)	29,590	8.59	3,175.72	5,414.28	31,757.20	27,071.40	29,238.60
29,170	16 kg/rai (480฿)	29,650	8.77	3,896.51	4,873.49	38,965.10	24,367.45	33,682.55
29,1700	18 kg/rai (540฿)	29,710	10.05	5,992.82	4,057.19	59,928.20	20,285.95	50,504.15

CHAPTER 5

DISCUSSION

Vegetative growth

Vegetative growth of cabbage in this study was indicated positively by the weekly leaf length (Table 7), weekly leaf width (Table 8) and weekly leaf area (Table 9) and the yield components namely stem diameter, number of wrapper leaves and frame leaves (Table 10) for different rates of nitrogen and plant spacings. While plant height (Table 6) was directly proportional to the rates of nitrogen application, it was however indirectly proportional to different plant spacings. No interaction was observed betwecn nitrogen application and different plant spacings in the vegetative growth of cabbage. The growth of cabbage was initially slow until 21 DAT but however, significant growth was observed in the plant height, leaf length, leaf width and leaf area from 28 DAT. This was due to the fact that the plants had recovered from the transplanting shock and started to develop its rooting system. The application of nitrogen to the plants at 20 DAT made a significant difference in their vegetative growth. Different rates of nitrogen and different plant spacings both proportionally contributed directly to the vegetative growth in the measured parameters except in the case of plant height in different plant spacings. The stem diameter was directly proportional to the biological and economical yield of cabbage. Increasing rate of nitrogen and increasing plant spacing also had an increasing effect on the stem diameter. The number of wrapper leaves was not affected by the rates of nitrogen and different plant spacings; which may be due to the varietal effect. Different levels of nitrogen also had no effect on the number of frame leaves but were directly affected by plant spacings. This may be due to the fact that wider plant spacing reduced competition for space and sunlight thus developing more frame leaves.

Similar studies conducted by Boroujerdnia and Ansari, (2007) reported that application of nitrogen fertilizers increased plant height in lettuce. The highest level of nitrogen produced the tallest plant. Leaf area also had a positive effect from the application of nitrogen with the highest leaf area obtained from the application of 120 kg N/ha. An investigation carried out by Gulsar, (2005) on spinach also showed that increase in the nitrogen dose from 0 to 150

kg/ha also increased the leaf area. Tariq *et al.*, (2011) reported that stem diameter generally increased with an increase in nitrogen rates in millet plants. Meena and Paliwal, (2003) also reported that stem diameter significantly increased with increasing levels of spacing in cabbage plants which is similar to the results obtained from this experiment. Khatiwada, (2000) in his study with cabbage reported that widest plant spacing produced the highest number of outer leaves (frame leaves) and was significantly different. Hasanuzzaman *et al.*, (2009) reported that maximum plant height was observed with the closest plants while the lowest plant height was observed with the widest spaced plants in rice. Meena and Paliwal, (2003) and RakshandaBhat *et al.*, (2007) also reported an increase in leaf number with increase in plant spacing. All these findings are in total agreement with the results obtained from this experiment.

Yield of cabbage

A positive response was observed in the biological and economical yield of cabbage by the different rates of nitrogen, different plant spacings and also from different pest control systems. Increasing rates of nitrogen had a direct effect on weight per head and biological and economical yield suggesting that nitrogen is essential to increase yield in cabbage crops. Economical yield with the highest rate (18 kg/rai) was 48.2% higher than the control plot having 0 kg N/rai while plot with 14 kg N/rai was 26.8% higher than the control and plot with 16 kg N/rai was 29.4% higher. Wider plant spacing was also directly proportionate to the biological and economical weight per head but was however indirectly proportional to the total yield. Highest yield was obtained with closer plant spacing due to higher number of plants per unit area while the highest head weight was obtained from wider plant spacing; which was due to reduced competition for nutrient, water and sunlight. Different pest control systems did not have any varying effect on the weight per head and biological or economical yield but they were however distinctive from the control plot. This was due to the fact that some degree of pest control was implemented in all the plots apart from the control and further suggesting the effectiveness in all the pest control systems implemented. No interaction between nitrogen application and plant spacing were observed suggesting that both variables acted independently to produce the obtained results.

Studies conducted by Meena and Paliwal, (2003) also reported an increase in head weight of cabbage with increase in plant spacing. They further reported a significant increase in biological and economical yields in closer spacing over wider spacing. Sharma and Chandra, (2002) reported that average head weight and head yield was found to increase with increasing levels of nitrogen. The average head weight was found significantly higher with wider spacing while the closer spacing gave significantly higher yields in cabbage. Similar findings were also reported by Mallik and Bhattacharya, (1996); Sandhu *et al.*, (1999) and RakshandaBhat *et al.*, (2007). Chweya, (1984) reported that interaction between nitrogen and plant spacing for yields was not significant in fodder rape crop. All these findings are consistent with the results obtained from this experiment.

Quality of cabbage

The quality characteristic of cabbage was measured by the head firmness (compactness), head height, head width, dry matter content, total soluble solid content, number of damaged frame leaves, number of damaged wrapper leaves and pest larvae count. Different levels of nitrogen had a positive effect on head firmness, head height and head width. Increased levels of nitrogen resulted in more compact and larger head size. This was due to the availability of more nutrients for the appropriate development of cabbage heads. Plot with 18 kg N/rai produced head size that was 48.74% higher than plot with 0 kg N/rai. Similarly they produced 15.70% more compacted heads then the control plot. While different plant spacings had no effect on head firmness, wider spaced plants produced larger head because of sufficient competition for nutrient and sunlight. Wider spaced plants (50 cm x 50 cm) produced head size which was 34.26% higher than the closest plant spacing (50 cm x 30 cm).

These results are in total agreement with similar studies undertaken by Sharma and Chandra, (2002) who reported that head size of cabbage increased with the increase in thc rate of nitrogen and with wider plant spacing. Similar findings were also reported by Kumar and Rawat, (2002) and Tendaj and Kuzyk, (2001). In a separate study conducted by Westerveld *et al.*, (2003), it was identified that head width and height increased with increasing nitrogen application which is consistent with the present findings.

While the dry matter content of cabbage was influenced by the rates of nitrogen, it was however not affected by different plant spacing. Increased nitrogen rates had a negative effect of cabbage percent dry matter content. Similar report was presented by Peck, (1981) where he stated increasing fertilizer nitrogen resulted in decrease in percent dry mass of cabbage head. Kumar and Rawat, (2002) reported that plant spacing had no effect on dry matter percentage of cabbages. Santamaria *et al.*, (1999) reported that the reduction in dry matter content by increasing nitrogen fertilizer can be attributed to replacement of organic acids and sugars by nitrate.

The total soluble solid content in cabbage heads were statistically unaffected by either nitrogen or different plant spacing. However, percent brix increased with an increase in nitrogen content by 13.04% in the plots applied with 18 kg N/rai when compared with the control plots receiving 0 kg N/rai. Acar *et al.*, (2008) also reported that nitrogen did not have any significant difference in the TSS of lettuce leaves. However, Kumar and Rawat, (2002) reported that nitrogen had significant effect on TSS of cabbage. The maximum TSS was recorded in the plots with maximum rates of nitrogen. Riad *et al.*, (2009) further reported that increasing nitrogen fertilization rate increased TSS but decreased dry matter content while plant density did not significantly affect both of these parameters. The fact that nitrogen did not have any significant effect on TSS in this experiment may be due to the using of low range of 2 kg N/rai between treatments; which may be less to show any significant effect.

The number of damaged frame and wrapper leaves showed significant effect between the treated plots and the untreated check. This was due to the effectiveness of the pest control system implemented in all three plots. The pest larvae count in the untreated check was the highest while in the plots with pest control was not statistically different. The results suggest that pest control is important to obtain quality cabbage heads however, only the best control system based on environment sustainability and long term benefits should be selected. Comparative studies undertaken by Burkness and Hutchison, (2008) for integrated pest management (IPM) and conventional (chemical) method of pest control identified that IPM program resulted in significantly lower percentage of plant infested than the conventional program or the untreated check. They further reported that pest reduction in the IPM program resulted in an average of 10.5% higher marketable yields than the conventional program. Results also indicated that IPM program reduced overall use of insecticide. The findings of Burkness and

Hutchison, (2008) is in partial agreement with the findings of this experiment whereby the control also recorded the highest pest incidence with the lowest yields but however, there was no statistical difference between the IPM plots and the conventional (chemical) plots. This may have been due to the effectiveness of abamectin against the lepidopteron cabbage pests. But the environmental and long term beneficial effects of IPM control system cannot be overemphasized. Krauss *et al.*, (2011) in a separate study concluded that organic farming increases biodiversity, including important functional groups like plants, pollinators and predators which enhance natural pest control. Preventative insecticide application in conventional fields has only short-term effects on aphid densities but long-term negative effects on biological pest control. Organic pest control system may however proof to become expensive due to higher labour input.

Food safety

Food safety generally consists of three major components; namely microbiological, accumulation of heavy metals and pesticide residual effects. The microbiological effects can be eliminated through following proper hygiene in the farm and throughout the supply chain while the elimination of heavy metals and pesticide residues can only be prevented from practice of appropriate farming systems during the production phase of commodities.

The presence of nitrate in vegetables, as in water and generally in other foods, is a serious threat to human health. Leafy vegetables are the main source of dietary nitrate intake in humans therefore it is important to produce vegetables with low nitrate content. The nitrate content in cabbage head in this experiment was directly proportional to the rate of nitrogen application and plant spacing. The highest rate of nitrogen and the widest plant spacing recorded the highest nitrate content in the heads. This may have been due to the plants in wider spacing having low plant density thus receiving more nitrogen per plant compared to higher density plants. Similar studies were undertaken by Aquino *et al.*, (2005) and reported that the increasing nitrogen rates caused an increase in the nitrate content of cabbage while a reduction in plant spacing caused a reduction in the nitrate content. El-Hassan, (1990); Jana *et al.*, (2010) and Ahmadil *et al.*, (2010) also reported similar findings in their work with lettuce, cabbage and spinach.

An Acceptable Daily Intake (ADI) for nitrate of 3.7 mg/kg bw/day, equivalent to 222 mg nitrate per day for a 60 kg adult was established by the former Scientific Committee on Food (SCF) and was reconfirmed by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) in 2002. In this experiment, the highest NO_3 content of 964.91 mg/kg was obtained from the plots with 18 kg N/rai. With the largest economical head size of 1.17 kg, the nitrate content per gram in the heads would be: 964.91 mg/1017 g = 0.95 mg/g NO_3 therefore, if a person consumes 200 g of cabbage in a day, his ADI would be 0.95mg x 200g = 190 mg NO_3 which is safe for a 60 kg person. This is below the Acceptable Daily Intake as approved by JECFA. Considering the fact that cooking reduces nitrate content, the ADI will reduce further in such circumstances. Prasad and Chetty, (2008) reported that boiling reduces nitrate content by 47-56%. Nitrate is soluble in water and washing of leafy vegetable can reduce nitrate levels by 10-15% (EFSA, 2008). Different European countries have also set maximum limits of NO_3 for trade in their countries. Austria has set a maximum limit of 1,500 mg/kg NO_3 for trade within their country. The NO_3 recorded from the experiment is within this limit therefore it is in a safe range and harmless for human consumption. Cabbage produced from using the GAP method implemented in the experiment can be successfully traded within the European countries.

Pesticides have been used in agriculture to increase production and quality of produce for decades. However, recently a lot of emphasis is being placed on the negative effects of pesticides. If not used responsibly, pesticides can be very detrimental to the environment and human health. However, pesticides will continue to play its role in producing food, feed and fibre to meet the demand from the increasing world population. It is therefore imperative to manage the use of pesticides within safe limits that are both sustainable and safe for environmental protection and human consumption. Appropriate pest control measures need to be implemented to achieve this goal.

Abamectin (80% avermectin B1a and 20% avermectin B1b) was used in the experiment to control lepidopteron pest of cabbage in comparatively with IPM and BT. Samples were analyzed for residue at 9 days after the last spraying. No pesticide residue was detected in the analyzed sample. This was due to the reason that the waiting period of 7 days was followed before harvesting the crop. It is therefore safe to say that cabbages sprayed with abamectin at the recommended spraying rate and harvested after 9 days are safe for human consumption.

The results from the experiment showed no statistical difference between the three pest control methods used. The best method that can be sustainably used in a GAP crop production program would be IPM. This is due to the reason that it uses an integrated approach combining different control methods thus avoiding the risk of building pest resistance against any particular control system (chemical and BT). Furthermore, IPM promotes environmental sustainability and allows a balance population of predators and parasites to ensure effective control. Use of chemical are the last resort in any IPM program therefore also reduces the risk of chemical exposure to the farmer and the farm labourers.

Cost of production

The cost of producing one rai of cabbage based on different nitrogen rates used in the experiment was calculated. The cost for agro-inputs and labour was 29,170฿; which was added with the cost of nitrogen from different rates 14 kg/rai (420฿), 16 kg/rai (480฿) and 18 kg/rai (540฿). The rates of P and K were fixed based on the soil analysis results. Highest gross margin (50,504.15฿) was obtained in the plots with the highest (18 kg/rai) level of nitrogen. This was due to the highest nitrogen level producing the highest yields. Malik and Bhattacharya, (1996) also reported that the highest gross margin was obtained with the highest nitrogen rate of 120 kg/ha.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Conclusion

Adoption of appropriate farming system is essential for the production of better quality crops that are safe for human consumption. While achieving higher yields is one of the important criteria in selection of appropriate production methods, the importance of environmental sustainability and food safety cannot be ignored. Various agro-inputs and farm management practices play a significant role in achieving this goal. Farmers therefore need information to make correct decisions to raise the profitability of their farms while producing crops according to the national/international set standards. GAP is one of such standards that ensure crops produced on farms and delivered to the consumers are free from microbiological contaminations while heavy metals and pesticide residues are at minimum residual levels as stipulated by codex and other international guidelines.

The results from the experiment proved that nitrogen influences the vegetative growth, yield, yield components, quality and nitrate content of cabbage. This was evident from the significant increase in plant height and leaf area after the application of nitrogen on 20 DAT. While the heaviest biological weight per head (2.28 kg), heaviest economical weight per head (1.13 kg), highest biological yield (118.26 tons/ha), highest economical yield (62.79 tons/ha), the most compacted head (6.19 kg/cm^2) and lowest percentage of unmarketable yields (40.37%) was produced in the plot with 18 kg N/rai. The plot with highest nitrogen application also had the highest nitrate content (964.91 mg/kg) in the leaves. This suggests that while nitrogen may be important to increase the growth, yield and yield components in cabbage, the excessive application can result in higher nitrate accumulation thus causing risk to human health and environment contamination.

Results from the experiment also proved that plant spacing also influences vegetative growth, yield components, quality and nitrate content of cabbage. The largest leaf area (1208.38 cm^2), highest biological weight per head (2.25 kg), highest economical weight per head

(1.17 kg), lowest unmarketable yield (36.66%) and highest nitrate content (653.52 mg/kg) was produced in the plot with widest plant spacing (50 cm x 50 cm) having a plant density of 40,000 plants per ha. While the highest biological yield (122.00 tons/ha) and the highest economical yield (63.64 tons/ha) with the lowest nitrate content (523.25 mg/kg) was produced in the plot with the closest plant spacing (50 cm x 30 cm) having a plant density of 66,667 plants per ha. This concludes that closer plantings will produce higher yields with small head size containing low nitrate content while wider spacing will produce larger heads with lower yields and higher nitrate contents.

Interaction between the nitrogen application and plant spacing was not significant in all the measured parameters except for the nitrate content in the leaves. The highest nitrate content (1084.73 mg/kg) in the interaction was recorded in the treatments with 18 kg N/rai and plant spacing of 50 cm x 50 cm.

Controlling pest is essential to obtain high yields and good quality cabbage heads. This was evident from the results of the experiment whereby all the treated plots recorded less pest infestation when compared with the untreated plots. Many literatures has indicated the detrimental effects of pesticide residue on human health, therefore, implementation of appropriate pest management system is important to harvest crops that are safe for human consumption. The integrated pest management system used in the experiment was successful since abamcctin was only sprayed once and there was no pesticide residue detected in the laboratory test of the harvested sample. While the plot where BT used was not significantly different from the IPM plots, however, using of only one chemical is risky in developing resistance towards the targeted pest. Abamectin plots were also not significantly different from the IPM plots but however, using of abamectin possess risk to farmers, farm labourers, environment and produces high chances of development of resistance amongst the targeted pests since DBM is known to be notorious in development of resistance to most of the pesticides used against them.

The highest gross margin per rai (50,504.15฿) was obtained from the plots with the treatments of 18 kg N/rai. The highest yield was recorded in the plots with plant spacing of 50 cm x 30, therefore a treatment combination of 18 kg nitrogen per rai in the plant spacing of 50 cm between rows x 30 cm within rows will give a maximum gross margin for cabbage.

Recommendations

Following recommendations as per the objectives of the experiment are made from the findings of this study:

1. The best nitrogen rate for growing of cabbage crop in soils which has NPK in the range (Percentage N – 0.4%, Available P – 783ppm and Extractable K – 121ppm) is 18 kg per rai.

2. For domestic markets where head size is not considered as important, a plant spacing of 50 cm between rows x 30 cm within rows should be used to obtain optimum yields.

3. For export markets where head is graded according to size, a plant spacing of 50 cm between rows x 50 cm within rows should be used to obtain larger head size and reduce rejects.

4. Integrated pest management should be used with regular monitoring of pest population in the field. Any chemicals used should be alternated and be target specific. Proper chemical withholding periods should be followed with correct spraying rates to obtain produce with low MRL of pesticides.

5. Recommended GAP package of practice for cultivation of cabbage is:

Cabbage variety:	C3557 (F1 hybrid)
Fertilizer requirement:	N - 39 kg urea/rai
	P - 30.5 kg/rai (0-46-0)
	K – 72 kg/rai (0-0-50)
	Poultry manure (320 kg/rai)
	Compost (80 kg/rai)
Plant spacing:	50 cm between rows x 30 cm within rows (Local market)
	50 cm between rows x 50 cm within rows (Export market)
Crop management:	Prepare raised bed, apply poultry manure and compost and mix well in the soil. After 2 weeks apply 19.5 kg urea, 30.5 kg phosphorus, 72 kg potash mix well, cover with plastic mulch

	and transplant 4 week old seedlings. Regular watering should be done.
Pest management:	Spray the beds with Nematode (*Steinernema carpocapsae*) at the rate of 75 grams in 20 liters of water per rai before covering with plastic. Place sticking yellow traps around the field at every 3 to 4 meters apart. Monitor the pest population and spray crop if population is above economic threshold of 10%. For first two sprayings use BT and abamectin for the third and then BT again. This will ensure low MRL and will also prevent pest resistance to BT and abamectin.
Expected yield:	10.05 tonnes per rai
Expected gross margin:	50,504.15฿

BIBLIOGRAPHY

Acar, B., M. Paksoy and M. Seymen. 2008. Irrigation and nitrogen level affect lettuce yield in greenhouse condition. **African Journal of Biotechnology**. 7(24): 4450-4453.

Adeniji. O. T., Swai and A. Aloyce. 2010. Evaluation of head yield and participatory selection of horticultural characters in cabbage. **Jour. of Plant Breeding & Crop Sci.** 2 (8): 243 – 250.

Aerts, M and M. Mossler. 2004. **Crop Profile for Cabbage in Florida**. [Online]. Available http://www.ipmcenters.org/cropprofiles/docs/FLcabbage.pdf. (02 August 2011).

Ahmadil, H., V. Akbarpour and A. Shojaein. 2010. Effect of different levels of nitrogen fertilizers on yield, nitrate accumulation and several quantitative attributes of five Iranian spinach accessions. **American-Eurasian J. Agric. & Environ. Sci.** 8(4): 468-473.

AOAC (Association of Official Analytical Chemists). 1984. **Determination of Total N in Soil by Kjeldahl Method.** USA: Association of Official Analytical Chemists: 350 p.

Aquino, L. A. de; M. Puiatti and M.R.S. Castro. 2005. Effect of spacing and doses of nitrogen on the qualitative characteristics of the yield of cabbage. **Horticultura Brasileira**. 23 (1): 100-104.

Arbuckle, T.E., D.A. Savitz and K.M. Curtis. 1999. Exposure to phenoxy herbicides and the risk of spontaneous abortion. **Epidemiology**. (10):752–760.

Asandhi, A. A. Schoorlemmer and I. Sulastrini. 2006. **Development of a Good Agricultural Practice to improve food and Product quality in Indonesian Vegetable Production**. [Online]. Available http://www.Asandhi/Schoorlemmer/andSulastrini/2006/ Development of a Good Agricultural Practice to improve food and Product quality Indonesian/Vegetable/Production/Hortin/Research/Report (03 August 2011)

Aulakh, M.S and C.A. Grant. 2008. **Intergrated Nutrient Management for Sustainable Crop Production.** New York. USA. The Haworth Press: 599p.

AVRDC (Asian Vegetable Research & Development Centre). 2001. **International cooperators' Fact Sheet: Bacterial soft rot.** [Online]. Available http://www.avrdc.org/ LC/cabbage/ softrot.html. (August 2011).

Bai, Y.H., L. Zhou and J. Wang. 2006. Organophosphorus pesticide residues in market foods in Shaanxi area, China. **Food Chemistry**. (98): 240–242.

Barker, A.V and D.J. Pilbeam. 2007. **Handbook of Plant Nutrition**. Taylor and Francis Group, USA: 613p.

Bashour, I. 2011. **Pesticide, Fertilizer and Food Safety**. [Online]. Available http://www. Afedonline.org/afedreport/English/book10.pdf. (07 August 2011).

Bediako-Asare, E., A.A. Quaye-Addo and A. Mohammed. 2010. Control of diamond back moth (*Plutella xylostella*) on cabbage (*Brassica oleracea var. capitata*) using intercopping with non-host crops. **American Jour of Food Technology** 5(4): 269-274.

Bellow, T.S. and Fisher, T.W. (eds). 1999. **Handbook of Biological Control**. San Diego, Academic Press, California: 1046p.

Belford, R.K., B. Klepper and R.W. Rickman. 1987. Studies of intact shoot root systems of field grown winter wheat. II. Root and shoot developmental patterns as related to nitrogen fertilizer. **Agron. Jour**. (79): 310–319.

Bhat, K.A., N.A. Bhat and P.A. Sheikh 2010. Studies on Status and host range of soft rot disease of cabbage (brassica olerancea var. Capitata in Kashmir valley. **Jour. of Phytology**. 2 (10): 55-59.

Bird, G.W., T. Edens and E. Groden. 1990. **Design of pest management systems for sustainable agricultural systems**. Cited In: Integrated Pest Management in the Global Arena, Maredia, K.M., D. Dakouo and D. Mota-Sanchez (Ed). 2003. CABI Publishing, Wallingford, UK: 512p.

Blackman, R.L. and V.F. Eastop. 1984. **Aphids on the World's Crops; An Identification guide.**, Chihester, UK. John Wiley: 312p.

Boroujerdnia, M. and N.A. Ansari. 2007. Effect of different levels of nitrogen fertilizer and cultivars on growth, yield and yield components of Romaine lettuce (lactucea sativa L.). **Middle Eastern and Russian Journal of Plant Science and Biotechnology**. 1(2): 47-53.

Brown, S.C., J.D.H. Keatinge and P.J.M. Cooper. 1987. Effect of fertilizer, variety and location on barley production under rainfed condition in Northern Syria. I. Root and shoot growth. **Field Crops Res.** (16): 53–66.

Bostick, W.M.N., V.B. Bado and J.W. Jones. 2007. Soil carbon dynamics and crop residue yields of cropping systems in the Northern Guinea Savanna of Burkina Faso. **Soil Till. Res.** (93): 138–151.

Burkness, E.C and W.D. Hutchison. 2008. Implementing reduced-risk integrated pest management in fresh-market cabbage: improved net returns via scouting and timing of effective control. **J. Econ. Entomol.** 101(2): 461-471.

Capinera, J.L. 2001. **Handbook of vegetable pests.** Academic Press, San Diego.729p.

Capinera, J. L. 2005. **Featured Creatures.** [Online]. Available http://entendept.ufl.edu/creatures/veg/leaf/cabbage_looper.htm. (01 August 2011).

Carvalho, F. P. 2006. Agriculture, Pesticide, Food security and food safety. **Environ. Sci. & Policy** (9): 685-692.

Chatupote, W and N. Panapitukkul. 2005. Regional Assessment on Nutrient and Pesticide leaching in the vegetable production area of Rattaphum catchment, Thailand. **Water, Air and Soil Pollution: Focus** 5 (1-2): 165-173.

Cherdchu, C. 2010. **Pesticides residue found in fruits and vegetables from Thailand.** [Online]. Available http://www.mst.or.th/images/14072010_Pesticide%20-chainarong2.pdf. (08 August 2011).

Chweya, J. A. 1984. Yield and quality of kale as affected by nitrogen side-dressing, spacing and supplementary irrigation. **Acta Horticulturae.** (163): 295-301.

Chu, Y.F, J. Sun. and R.H. Liu. 2002. Antioxidant and antiproliferative activities of common vegetables. **Jour. of Agrl. and Food Chemistry** (50): 6910-6916.

Chumakov, M.A. and T.L. Kuznetsova. 2009. **Economic plants and their disease, pests and weeds.** [Online]. Available http://www.agroatlas.ru/en/content/pests/Helicoverpa_Armigera. (01 August 2011).

Cranshaw, W.S. 2006. **Flea Beetles.** [Online]. Available http://www.ext.colostate.edu/pubs/insect/05592.html. (01 August 2011).

Crouse, D. 2011. **Ensuring sustainability of our agricultural production system.** [Online]. Available http://nutrients.soil.ncsu.edu. (04 August 2011).

Cole, D.C., F. Carpio and N. Leon. 1997. Dermatitis in Ecuadorean farm workers. **Contact Dermatitis.** (37):1–8.

Coresta, 2005. **Good Agricultutal Practices (GAP) Guidelines. Guide no. 3.** [Online]. Available http://www.coresta.org/Guides/Guide-No3-GAP_Feb05.pdf. (04 August 2011).

Cox, C. 1996. Pesticides and male fertility. **Journ. Pestic. Rev.** 16(2): 2–7.

Daugovish, O., M. Cahn and E. Takele. 2008. **Cabbage Production in California.** [Online]. Available http://www.anrcatalog.ucdavis.edu. (25 January 2010).

DeBach, P. and D. Rosen. 1991. **Biological control by natural enemies.** UK. Cambridge University Press: 440p.

Delannoy,G. 2001. Leafy Vegetables In: Control of diamond back moth (Plutella xylostella) on cabbage (Brassica oleracea var capitata) using intercropping with non-host crops. **American Jour. of Food Tech.** 5(4): 269-274.

Dhillon, K.S. and S.K. Dhillon. 1997. Distribution of seleniferous soils in north west India and associated toxicity problems in the soil- plant-animal-human continuum. **Land contamination and Reclamation.** (5): 313-322.

Dhillon, K.S. and S. K. Dhillon. 2003. Distribution and management of seleniferous soils. **Advances in Agronomy.** (79): 119-184.

Dixon, G. R. 2007. **Vegetables brassicas and related crucifer.** CABI, Oxfordshire, UK. p. 327.

Doles, J.L., R.J. Zimmerman and J.C. Moore. 2001. Soil microarthropod community structure and dynamics in organic and conventionally managed apple orchards in Western Colorado, USA. **Journ. Of Applied Soil Ecol.** (18): 83-96.

Du, L., T. Zhao and M. Ma. 2011. Investigations on nitrate pollution of soil, groundwater and vegetables from three typical farmlands in Beijing Region, China. **Agric. Sci. in China.** 10 (3): 423-430.

EFSA (European Food Safety Authority). 2008. Opinion of the Scientific Panel on Contaminants in Food Chain on a request from the European Commission to perform a scientific risk assessment on nitrate in vegetables. **The EFSA Jour.** (69): 1-79.

Elbetieha, A and D. I. Sahar. 2003. Assessment of antifertility activities of abamectin pesticide in male rats. **Ecotoxicology and Environ. Safety.** (55): 307–313.

El-Hassan, E.A.A. 1990. Yield and nitrate content of lettuce in relation to some cultural practices. **Bulletin of Faculty of Agriculture, University of Cairo.** 41(2): 407-417.

EPA (USA Environmental Protection Agency). 2011. **Food Safety.** [Online]. Available http://www.epa.gov/agriculture/tfsy.html. (09 August 2011).

European Commission. 2002. **Risk profile on the microbiological contamination of fruits and vegetables eaten raw.** [Online]. Available http://ec.europa/food/fs/sc/scf/out123_en. pdf (07 August 2011).

FAO (Food and Agriculture Organization) and WHO (World Health Organization). 2011. **Codex alimentarius.** [Online]. Available http://www.codexalimentarius.net/web/index_en.jsp. (04 August 2011).

_____. 2005. **Pesticide Residues in Food.** [Online]. Avaialble http://www.codexalimentarius. Net/mrls/servlet/Pesticidesservlet?Pesticide/substancedomain/2Fpestdes_q-e.htm. (08 August 2011).

FAO. 2008. **Good Agricultural Practices.** [Online]. Available http://www.fao.org/prods/gap. (04 August 2011).

_____. 2003. Report of the Expert Consultation on a Good Agricultural practices (GAP) Approach. [Online]. Available http://www.fao.org/prods/gap/Docs/PDF/1-reportExpertConsultationEXTERNAL.pdf. (09 August 2011).

_____. 2002. **International code of conduct on the distribution and use of pesticides.** [Online]. Available http://www.fao.org/fileadmin/templates/agphome/documents Pests_Pesticides/Code/code.pdf (August 2011).

_____. 2000. **Cabbage Intergrated Pest Management: An Ecological Guide.** N.P. n.p. 205p.

_____. 1999. **The state of food insecurity in the world.** [Online]. Available http://www.fao.org/docrep/007/x3114e/x3114e00.htm. (09 August 2011).

Gaya, U. I. and S. Alimi. 2006. Spectrophotometric determination of nitrate in vegetables using phenol. **Jour. Appl. Sci. Environ. Mgt.** 10 (1): 79-82.

Garcia-Gimeno, E., V. Andren and R. Bolnda. 1996. Heavy metal incidence in the application of inorganic fertilizers and pesticides to rice farming soils. **Environ. Pollution.** 92(1):19-25.

Gastal, F and G. Lemaire. 2002. N uptake and distribution in crops: an agronomical and ecophysiological perspective. **Journ. Exp. Bot.** (53): 789–799.

Giles, J. 2004. Is organic food better for us. **Nature.** (428): 796-797.

GOBAL GAP. 2009. **General Regulations Intergrated Farm Assurance, Version 3.1.** [Online]. Available http://www.globalgap.org. (04 August 201).

Goodell, G. 1984. **Challenges to international pest management research and extension in the Third world: do we really want IPM to work?** Cited In: Integrated Pest Management in the Global Arena, Maredia, K.M., D. Dakouo and D. Mota-Sanchez (Ed). 2003. Wallingford, UK. CABI Publishing: 512p.

Greenwood, D.J and J. Hunt. 1986. Effect of nitrogen fertilizer on the nitrate contents of field vegetables grown in Britain. **Journ. Of the Sci. of Food and Agric.** (37): 373-383.

Gulser, F. 2005. Effect of ammonium sulphate and urea on $NO3^-$ and $NO2^-$ accumulation nutrient contents and yield criteria in spinach. **Scientia Horticulturae.** (106): 330-340.

Hamilton, J.T. and R.B. Toffolon. 2003. **Insect pests of crucifer vegetables.** [Online]. Available http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/126485/insect-pests-crucifer-vegetables.pdf. (01 August 2011).

Hanada, T. 1991. **The effects of mulching & row cover on vegetable production.** Japan Chugoku Agr. Exp. Stn. Ayabe: 23p.

Hasanuzzaman, M., M.L. Rahman and A.S.M. Zobaer. 2009. Plant characters, yield components and yield of late transplanted Aman rice as affected by plant spacing and number of seedling per hill. **Advances in Biological Research.** 3(5-6): 201-207.

Haynes, R.J and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. **Nutr. Cycl. Agroecosys.** 51, 123–137.

Hernando, M.O., J.J. Suarez-Barcena and A.R. Fernandez-Alba. 2007. Fast separation liquid chromatography–tandem mass spectrometry for the confirmation and quantitative analysis of avermectin residues in food. **Journ. of chromatography A** (1155): 62-73.

Hill, T.A. and R.E. Foster. 2000. Effect of insecticides on the Diamondback moth (Lepidoptera: Plutellidae) and its parasitoid *Diadegma insulare* (hymenoptera: Ichneumonidae). **Hort. Entomology.** 93(3): 763-768.

Hopenhayn-Rich, C., M.L. Stump and S.R. Browning. 2002. Regional assessment of atrazine exposure and incidence of breast and ovarian cancers in Kentucky. **Arch Environ Contam Toxicol.** (42):127–136.

Horrigan, L., S.L. Robert and P. Walker. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. **Environ. Health Perspect.** (110): 445-456.

Infante-Rivard, C., D. Labuda and D. Sinnett. 199. Risk of childhood leukemia associated with exposure to pesticides and with gene polymorphisms [comment]. **Epidemiology.** (10):481–487.

Isely, D. 1957. **Methods of Insect control: Part I and II, revised,** Cited by Braun, B and A. Arbor In: Integrated Pest Management in the Global Arena, Maredia, K.M., D. Dakouo and D. Mota-Sanchez (Ed). 2003. Wallingford, UK. CABI Publishing: 512p.

Jackson, C. G., G.D. Butler Jr and D.E. Bryan. 1969. Time required for development of *Voria ruralis* and its host, the cabbage looper, at different temperatures. **Jour. of Economic Entomology** (62): 69-70.

Jakse, M. and R. Mihelic. 1999. The influence of organic and mineral fertilization on vegetable growth and N availability in soil: preliminary results. **Acta Hort.** 506: 69-75.

Jana. J.C., S. Guha and R. Chatterjee. 2010. Effect of planting geometry and nitrogen levels on crop growth, fruit yield and quality in okra grown during early winter in terai zone of West **Bengal. J. Hort. Sc.** 5(1): 30-33.

Jones, J.B. and W.J.A. Steyn. 1973. **Sampling, handling and analyzing plant tissue samples.** Cited in: Barker, A.V. and D.J. Pilbeam. 2007. Handbook of Plant Nutrition. USA. Taylor and Francis Group: 613p.

Julient, N. 2008. **Use of inorganic fertilizers in Uganda.** [Online]. Available http://www.ifpri. org/publication/use-inorganic-fertilizers-uganda. (05 August 2011).

Kanaan, S.S. and C.D. Economakis. 1992. Effect of climatic conditions and time of harvest on growth and tissue nitrate content of lettuce in nutrient film culture. **Acta Hort. (ISHS).** (323):75-80.

Kang, G.S., V. Beri and B.S. Sidhu. 2005. A new index to assess soil quality and sustainability of wheat based cropping systems. **Journ. Of Biol. Fertil. Soils.** (41): 389-398.

Khatiwada, P.P. 2000. Plant Spacing: A Key Husbandry Practice for Rainy Season Cabbage Production. **Nepal Agric. Res. J.** (4-5):48-55.

Kirk, A.A., G. Mercadier and C. Rincon. 2004. Variability in Plutella and its natural enemies: implications for biological control. Cited In: Biological control of the diamondback moth, Plutella xylostella: A review. By: Sarfraz, M., A. Keddie and L.M. Dosdall. 2005. **Blocontrol Science and Technology**. 15(8): 763-789.

Kobryn, J. 1987. Productivity of some crisp head lettuce cultivars in relation to sowing date and plant density in Autumn- Winter green house production. **Eeszyty Nacekowe Akadimii Rolnictej VBin. Hugona Kollataj-w- Krakowie grednictwo Warsaw Poland.** (210): 163-183.

Kratky, B. A., J. K. Wang and K. Kubojiri. 1982. Effects of container size, transplant age and plant spacing on Chinese cabbage. **Jour. of the American Society for Hort Sci.** 107(2): 345-347.

Krauss, J., I. Gallenberger and I. Steffan-Dewenter. 2011. Decreased Functional Diversity and Biological Pest Control in Conventional Compared to Organic Crop Fields. **PLoS ONE** 6(5): 1371-1381.

Kucharek, T. 2004. **Disease Control in Crucifers: Broccoli, Brussels Sprouts, Cabbage, Cauliflower, Chinese Cabbage, Collards, Kale, Mustard, Radish, Rutabaga, Turnip (*Brassica* and *Raphanus* spp.).** [Online]. Available http://edis.ifas.ufl.edu/ PG045. (02 August 2011).

Kumari, B., V.K. Madan and T.S. Kathpal. 2002. Monitoring of seasonal vegetables for pesticide residues. **Environmental Monitoring and Assessment. (74)**: 263–270.

Kumar, M. and T.S. Rawat. 2002. Effect of nitrogen and spacing on the quality and yield of cabbage (*Brassica oleracea L. var. capitata*). **Agri. Sci. Digest.** 22 (2): 90-92.

Kwartery, J.A. and M.J. Towler. 1994. **West African Agriculture**. UK. MacMillan Education Ltd: 420p.

Lakwah, E., E.A. Hamed and A.A. Shams El-Din. 1995. Determination of certain organchlorine and organophosphorous pesticide in home-produced tomatoes and cucumber used for consumption in two Egyptian governorates. **Annals of Agricultural Science.** (33): 399–407.

Landis, D., S. D. Wratten and G. Gurr. 2000. Habitat manipulation to conserve natural enemies of arthropod pest in agriculture. **Annual Review of Entomology.** (45): 173-199.

Lesile, A.R. and G.W. Cuperus. 1993. **Successful Implementation of integrated pest management for agricultural crops.** Boca Raton, Florida. CRC Press: 193p.

Lester, G.l.D. 2006. Environmental regulation of human health nutrients (ascorbic acid, B-carotene and folic acid) in fruits and vegetables. **Hort Sciences.** (41): 59-64.

Levario-Carillo, M., A. Feria-Velasco and F.J. Solis. 2001. Parathion, a cholinesterase-inhibiting pesticide induces changes in tertiary villi of placenta of women exposed: a scanning electron microscopy study. **Gynecol Obstet Invest.** (52):269–275.

Li, P.K., Q.Z. Li and Y.L. Shao. 2004. Study on cleaning out residue of organophosphorous insecticides in peach. **Pesticide Science and Administration**. 25(6): 16–20.

Liou, T. D. 1984. Effect of plant density on the yield of taro in paddy field. **Jour. of Agric. Research China**. 33(1): 38-43.

Liu, S., X. Wang and Z. Shi. 2000. Seasonal abundance of the parasitoid complex associated with the diamondback moth, Plutella xylostella (Lepidoptera:Plutellidae) in Hangzhou, China. **Bulletin of Entomological Research.** (90):221-231.

Lopez-perez, A., E. Casanova and J.R. Guerrero. 1990. Residual effect of three phosphate rocks from Tachina (Venezuela) in a greenhouse experiment with maize (Zea mays L.) as indicator plant. **Revista-Cientifica- UNET** 4 (1–2): 29–48.

Lum, J. 2008. **Pesticide residue in food. Food safety Focus (21).** [Online]. Available http://www.cfs.gov.hk/english/multimedia/multimedia_pub/multimedia_pub_fsf_21_02.html (10 July 2011).

Lundberg, J.O., E. Weitzberg and M.T. Gladwin. 2008. The nitrate-nitrite-nitric oxide pathway in physiology and therapeutics. **Nature Reviews Drug Discovery.** (7): 156-167.

Lundberg, J.O., E. Weitzberg and N. Benjamin. 2004. Nitrate, bacteria and human health. **Nat. Rev. Microbiol.** (2): 593-602.

Mader, P., A. Flie-Bach and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. **Science.** (296): 1694-1697.

Maene, L.M., K.E. Sukalac and P. Heffer. 2008. **Global Food Production and Plant Nutrient Demand: Present Status and Future Prospects. In: Intergrated Nutrient Management for Sustainable Crop Production**. Aulakh, M.S. and Grant, C.A, (eds). New York, USA. The Haworth Press: 599p.

Mallik, S. C and B. Bhattacharya. 1996. Effect of different levels of nitrogen and different spacings on growth and yield of cabbage. **Environment and Ecology**.14 (2): 304-306.

Maredia. K.M., S.H. Gage and T.M. Wirth. 1992. Ecological observations on predatory Coccinellidae in southwestern Michigan. **The Grate Lakes Entomologist**. (25): 265-270.

Maredia, K.M., D. Dakouo and D. Mota-Sanchez. (Ed). 2003. **Integrated Pest Management In the Global Arena.** Wallingford, UK. CABI Publishing: 512p.

Maredia, K.M. 1997. **Sustaining host plant resistance derived tbrough conventional and biotechnological means**. Cited In: Integrated Pest Management in the Global Arena, Maredia, K.M., D. Dakouo and D. Mota-Sanchez (Ed). 2003. Wallingford, UK. CABI Publishing: 512p.

Maredia, K.M. and J.A. Mihn. 1994. **Intergrated management of stored grain insect pests in developing countries**. Cited In: Integrated Pest Management in the Global Arena, Maredia, K.M., D. Dakouo and D. Mota-Sanchez (Ed). 2003. Wallingford, UK. CABI Publishing: 512p.

Matt, K. J. 1970. Colorimetric determination of phosphorus in soil and plant materials with ascorbic acid. **Soil Science** 109(4): 214:220.

Mccollum, W. 1968. **Producing vegetable crops**. Illinois, USA. The interstate Printers & Publishers, Inc: 558p.

McLaughlin, M.J., D.R. Parker and J.M. Clarke. 1999. Metals and micronutrients-food safety issues. **Fleld Crops Research**. (60): 143-163.

Meena, K. K and R. Paliwal. 2003. Effect of different spacings on growth and yield of cabbage. **Annals of Agrlcultural Research**. 24 (2): 423-425.

Michalski, R. and I. Kursyca. 2005. Determination of nitrogen species (Nitrate, nitrite and ammonia ions) in environmental samples by ion chromatography. **Polish Jour. of Envlron. Studies**. 15 (1): 15-18.

Minks, A.K. and P. Harrewijn. 1987. **Aphids: Their Biology, Natural enemies and control. World crop pests.** [Online]. Available http://www.worldcat.org/title/aphids-their-biology-natural-enemies-and-control/oclc/13360853. (07 February 2011).

Moniruzzaman, M. 2006. Effects of plant spacing and mulching on yield and profitability of lettuce. **Jour of Agric. and Rural Dev. Bangladesh.** 4(1): 107-111.

Monteiro, A and T. Lunn. 1998. **Trends and perspectives of vegetable brassica breeding.** World Conference on Horticultural Research. 17- 20 June 1998. Rome, Italy.

Moya, J., K.G. Garrahan and G.S. Durell. 1998. Effects of cooking on levels of PCBs in the Willets of Winter Flounder. **Environmental Contamination and Toxicology**. (60): 845–851.

Nantachit. K. and D. Winijkul. 2007. Nitrate and nitrite contents of vegetables marketed in Chiangmai province. **CMU. J. Nat. Sci.** 6 (20): 349-353.

NGMC (New Guyana Marketing Cooperation). 2004. **Post harvest handling technical series. Technical bulletin No. 25.** [Online]. Available http://pdf.usaid.gov/pdf_docs/ PNACY841.pdf (02 August 2011).

Nilsson, T. 1980. The influence of soil type and irrigation on yield, quality and chemical composition of cauliflower. **Swedish Jour. of Agri. Research.** (10): 65-75.

Nonnecke, I. L. 1989. **Vegetable Production.** New York, USA. Van Nostrand Reihold: 657p.

Ogbodo, E.N., Okorie, P.O and Utobo, E.B. 2009. Evalution of the adaptability of cabbage (Brassica oleracae L. Var. Capitata) to the agro-ecology of Ebong state, southeastern Nigeria. **Intern. Journal of Sustainable Agric.** 1(2): 41-48.

PANUPS (Pesticide Action Networks Updates Services). 1997. **Pesticide use in Thailand.** [Online]. Available http://archive.sare.org/sanet-mg/archives/html-home/18-html/0405.html. (09 August 2011).

Pathak, R.K. and R.A. Ram. 2003. **Seminar Paper on Production and export of Organic frults and Vegetables in Asla.** [Online]. Available ftp://ftp.fao.org/docrep/fao/006/ad429e/ ad429e00.pdf (13 June 2011).

Paulsen, E. 1998. Occupational dermatitis in Danish gardeners and greenhouse workers (II). Etiological factors. **Contact Dermatitis.** (38):14–19.

Peck, N.H. 1981. Cabbage plant response to nitrogen fertilization. **Agron. Journal**. (73): 679-684.

Pervez, M.A., C. M. Ayub and N. Mahmood. 2004. Effect of nitrogen levels and spacing on growth and yield of Radish (*Raphanus sativus*. L.). **International Jour. of Agric. & Biol.** 6(3): 504-506.

Pesatori, A.C., J.M. Sontag and A. Blair. 1994. Cohort mortality and nested case control study of lung cancer among structural pest control workers in Florida (United States). **Cancer Causes Control**. (5):310–318.

Pimentel, D. (ed). 1997. **Techniques of reducing Pesticide Use: Economic and environmental Benefits.** New York, USA. John Wiley & Sons: 444p.

Prasad, S. and A. A. Chetty. 2008. Nitrate-N determination in leafy vegetables: Study of the effects of cooking and freezing. **Food Chemistry** (106): 772–780.

Premuzic, Z., A. Garate and I.Bomilla. 2002. Yield and quality of greenhouse lettuce as affected by form of N fertilizer and light. Cited in Nitrates in vegetables: Scientific opinion of the panel on contaminants in the food chain. **EFSA Journ.** (689): 1-79.

Pogoda, J.M and S. Preston-Martin . 1997. Household pesticides and risk of pediatric brain tumors. **Environ Health Perspec**. 105(11):1214–1220.

Poramacom, N. 20011. Pesticide market and related situations in Thailand. **Kesetsart Journ. (Soci. Sc)** (22): 205-211.

Pozo, O.J., J.M. Marin and F. Herna´ndez. 2003. Determination of abamectin and azadirachtin residues in orange samples by liquid chromatography–electrospray tandem mass Spectrometry. **Journ. of Chromatography A.** (992): 133–140.

Pullemand, M., A. Jongmans and J. Bouma. 2003. Effects of organic versus conventional arable farming on soil structure and organic matter dynamics in marine loam in the Netherlands. **Soil Use Managt.** (19): 157-165.

Rademaker, M. 1998. Occupational contact dermatitis among New Zealand farmers. **Australas Journ. Dermatol.** (39):164–167.

RakshandaBhat, J.P. Singh and Munib-ur-Rehman. 2007. Effect of nitrogen levels and spacing on the growth and yield of Chinese cabbage (*Brassica rapa* L. varPerkinensis). **Environment and Ecology**. 25 (1): 153-155.

Ramakrishna, A., H.M. Tam and T.D. Long. 2006. Effect of mulch on soil temperature, moisture, weed infestation & yield of groundnut in northern Vietam. **Field Crops Research.** (95): 115-125.

Reganold, J.P., L.F. Elliott and Y.L. Unger. 1987. Long-term effects of organic and conventional farming on soil erosion. **Nature.** (330): 370-372.

Relf, D., A. McDoniel and V. Tech. 2002. Fertilising the vegetable garden. [Online]. Available http://www.indiaagronet.com/indiaagronet/Manuers_fertilizers/contents/inorganic_fertilizers.htm (06 August 2008).

Raicevic, V., I. Kljuvev and J. Petrovic. 2010. **Microbial Contamination of Irrigation water, frults and vegetables.** [Online]. Available http//www.cropwat.agrif.bg.ac.rs. (27 September 2011).

Rosen, C.J and R. Eliason. 2009. Nutrient Managemnt for commercial fruits and vegetable crops in Minnesota. [Online]. Available http://www.extension.umn.edu/distribution/cropsystems/dc5886.html. (05 August 2011).

Rubatzky, V. E and M. Yamaguchi. 1997. **World vegetables: Principles, Production and nutritive values.** 2nd edition. New York, USA. Chapman & Hall: 843p.

Ruesink, W.G. 1997. **Status of systems approach to pest management.** Cited In: Integrated Pest Management in the Global Arena, Maredia, K.M., D. Dakouo and D. Mota-Sanchez (Ed). 2003. Wallingford, UK. CABI Publishing: 512p.

Sandhu, K. S., B.S. Chahal and M.S. Sandha. 1999. Effect of population density and nitrogen on growth characters and yield of cabbage (*Brassica oleracea* var. *capitata*). Vegetable Science. 26(2): 146-148.

Sanborn, M., D. Cole and K. Bassil. 2004. **Systematic review of pesticide human health effects.** [Online]. Avaialble http://www.ocfp.on.ca/local/files/Communications/Current/Issues/ Pesticides/Final/Paper/23APR2004.pdf. (08 August 2011).

Santamaria, P. 2008. Nitrate in vegetables: toxicity, content, intake and EC regulation. **Jour. of the Sclence of Food and Agriculture.** 86: 10-17.

Santamaria, P., A Elia and E. Todaro. 1999. A survey of nitrate and oxalate in fresh vegetables. **Journ. Sci. Food and Agric.** (79): 1882-1888.

Sarfaraz, M., A. Keddie and L.M. Dosdall. 2005. Biological control of the diamondback moth, Plutella xylostella: A review. **Biocontrol Science and Technology**. 15(8): 763-789.

Sarkar, S., S.R. Singh and R.P. Singh. 2003. The effect of organic and inorganic fertilizers on soil physical condition and the productivity of a rice–lentil cropping sequence in India. **Journ. Agric. Sci.** (140): 419–425.

Shao-ting, D. U., Y. Zhang and X. Lin. 2007. Accumulation of Nitrate in vegetables and its possible implications to human health. **Agricult. Sci. in China**. 6(10): 1246-1255.

Sharma, A and A. Chandra. 2002. Effect of crop geometry and nitrogen on vegetative growth and yield of cabbage. **Current Agriculture**. 26 (1-2): 99-101.

Shelton, A.M. 2004. Management of the diamondback moth. In: Biological control of the diamondback moth, Plutella xylostella: A review by: Sarfraz, M., A.B. Keddies and L.M. Dosdall. 2005. **Biocontrol Science and Technology**. 15(8): 763- 789.

Shelton, A. M., J.A.Wyman and S.D. Eigenbrode. 1993. Insecticide resistance of diamondback moth (Lepidoptera: Plutellidae) in North America. **Jour. Econ. Entomol.** (86): 11-19.

Shen, G.X., F.Y. Ke and J.Q. Zhang. 2002. Investigation and evaluation of the contents of pollutants in greenhouse vegetables in Shanghai. **Shanghai Environmental Sciences.** (21): 475–477.

Smittle, D.A. 1994. Irrigation regimes affect cabbage water use and yield. **Jour. of the American Society for Hort. Sci.** (119): 20-23.

Smith, R.C. 2010. **Vegetable Maturity Dates, Yield and Storage**. [Online]. Available http://www.ag.ndsu.edu/pubs/plantsci/hortcrop/h912.pdf. (02 August 2011).

Speijers, G.J.A. 1996. Nitrate, in **Toxicological evaluation of certain food additives and contaminants in food.** (Ed) World Health Organization, Food Additives Series 35, Geneva. pp 325–360.

SPRAMM (Specific Pesticide Residues Analytical Method Manual) -007-V1.0. 2004. Determination of Abamectin in Fruits and Vegetables Using HPLC with Fluorescence Detection. **Protocol for abamectin.** (11): 1-7.

Sun, X.G., G.H. Wu and J. Meng. 2003. Survey of organophosphorus pesticide residues in vegetables and fruits in Beijing. **Chinese Journal of Food Hygiene.** (15): 536–538.

Tabashnik, B.E., N.L. Cushing and M.W. Johnson. 1990. Field development of resistance to *Bacillus thuringiensis* in diamondback moth (Lepidoptera: Plutellidae). **Jour. Econ. Entomol**. (83): 1671-1676.

Talekar, N.S. 2000. **Chinese cabbage**. Proceedings of the 1st International Symposium on Chinese Cabbages. AVRDC, Shanhua, Tainan, Taiwan. pp. 67-69.

Talekar, N.S and A.M. Shelton. 1993. Biology, ecology, and management of the diamondback moth. **Annual Review of Entomology**. (38):275-301.

Tannenbaum, S.R., P. Walstrap. 2000. **Handbook of Water Analysis**, Nollet, L.M and M. Dekker (Ed), New York, USA. 212p.

Tariq, M., M. Ayub and M. Elahi. 2011. Forage yield and some quality attributes of millet (*Pennisetum amercannum* L.) hybrid under various regimes of nitrogen fertilization and harvesting dates. African Journal of Agricultural Research 6 (16): 3883-3890.

Tatchell, G.M., 1989. An estimate of the potential economic losses to some crops due to aphids in Britain. **Crop Protection**. (8): 25–29.

Tendey, M. and K. Kuzyk. 2001. Effect of plant density on yielding of cabbage. **Veg. Crops Research Bulletin**. 54 (2): 35-39.

Thompson, J.K. 2002. Yield evaluation of cabbage varieties. **Journ. Agric. Technol**. (5):15-19.

Tindall, H.D. 1993. **Vegetables in the Tropics**. Macmillan. Hampshire: 575p.

Torres, C.M., Y. Pico and J. Manes. 1996. Determination of Pesticide Residues in Fruits and Vegetables, **Journ. Chromatog**. A, 754: 301-331.

Van Eysinga, R. 1984. Nitrate and glasshouse vegetables. **Fertilizer Research**. (5):149-156.

Van Reeuwijk, L. P. 1987. **Procedures for Soil Analysis**. 2nd ed. Germany: International Soil Reference and Information Center. 25p.

Verkerk, R.H.J and D.J. Wright. 1996. Multitrophic interactions and management of the diamondback moth: **A Review. Bulletin of Entomological Research**. (86):205-216.

Vos, J.G.M., T.S. Uhan and R. Sutarya. 1995. Integrated crop management of hot peper (capsicum *spp.*) under tropical lowland conditions: Effects of rice straw and plastic mulches on crop health. **Crop Protection Jour**. (14) 6: 445-452.

Vural, H., D. Esiyok and I. Duman. 2000. **The culture of vegetables (Vegetable growing)**. Izmir, Turkey. 440p.

Walker, J.C. 1952. **Diseases of vegetable crops.** New York, USA. McGraw-Hill Book Company: 529p.

Wang, Z.H., Z.Q. Zong and B.M. Chen. 2002. Nitrate accumulation in vegetables and its residual in vegetable fields. **Environ. Sci.** (23): 79–83.

Wannamolee, W., no date. **Development of Good Agricultural Practices (GAP) for fruits and vegetables in Thailand.** [Online]. Available http://www.Wammamolee/DevelopmentofGoodAgriculturalPractices/GAP/forfruitsandvegetablesinThailandNationalbureauofAgriculturalCommodityandFoodStandards/Bangkok/Thailand. (09 Feburary 2011).

Weightman, R.M., C. Dyer and D.S. Farrington. 2006. Effects of light level, time of harvest and position within field on the variability of tissue nitrate concentration in commercial crops of lettuce (Lactuca sativa) and endive (Cichorium endiva). **Food Addit.Contam.** (23): 462-469.

Westerveld. S.M., M.R. McDonald and A.W. McKeown. 2003. Optimum Nitrogen Fertilization of Summer Cabbage in Ontario. **Acta Hort.** (627): 211-215.

WHO (World Health Organization). 2011. **Food Safety.** [Online]. Available http://www.euro.who.int/en/what-we-do/health-topics/disease-prevention/food-safety. (09 August 2011).

Willies, Q.G. 2011. **Effect of organic and inorganic fertilizers and their combinations on the growth and yield of maize in the semi-decricluous forest zone of Ghana**. Master's thesis College of Agriculture and natural Resources, Kwame Nkrumal University of science & technology, Kumasi, Ghana.

Worthington, V. 1998. Effect of agricultural methods on nutritional quality: a comparison of organic with conventional crops. **Alternative Theraples Health Med.** 4 (1): 58-69

Worthington, V. 2001. Nutritional quality of organic versus conventional fruits, vegetables and grains. **Jour. Alternative Complent. Med.** (7): 161-173.

Yentongchai, W. 1995. **Analysis of 32 Organophosphorus in Insecticides in Chainese Kale by Using Multiresidue Method.** Toxic Substances Report. 223p.

Yu, X.Y., F. Chen and X. Zhang. 2005. Removal of 3 organophosphorous insecticide residues with ozone and its influence on the content of Vc and carotenoid in vegetables. **Journ. of Northwest Sci-Tech University of Agriculture and Forestry.** 33(11): 150–154.

Zhang, Z.Y., X.Y. Liu and X.Y. Hong. 2006. Effects of home preparation on pesticide residue in cabbage. **Food Control**. (8): 1484-1487.

APPENDICES

APPENDIX A

The ANOVA Table and DMRT for cabbage yield (ton/ha)

Dependent Variable: marketable yield tones/ha

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	19	6911.102711	363.742248	3.97	0.0038
Error	16	1466.169244	91.635578		
Corrected Total	35	8377.271956			

R-Square	Coeff Var	Root MSE	yield Mean
0.824982	17.91922	9.572647	53.42111

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	1681.188356	840.594178	9.17	0.0022
fert	3	1910.639067	636.879689	6.95	0.0033
fert*rep	6	1051.939467	175.323244	1.91	0.1403
den	2	1986.981422	993.490711	10.84	0.0011
fert*den	6	280.354400	46.725733	0.51	0.7922

Tests of Hypotheses Using the Anova MS for fert*rep as an Error Term

Source	DF	Anova SS	Mean Square	F Value	Pr > F
rep	2	1681.188356	840.594178	4.79	0.0570
fert	3	1910.639067	636.879689	3.63	0.0838

t Tests (LSD) for marketable yield

NOTE: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	91.63558
Critical Value of t	2.11991
Least Significant Difference	9.5663

Means with the same letter are not significantly different.

t Grouping	Mean	N	fert
A	62.791	9	3
A	54.822	9	2
A	53.716	9	1
B	42.356	9	0

The ANOVA Procedure

t Tests (LSD) for marketable yield

NOTE: This test controls the Type I comparison wise error rate, not the experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	16
Error Mean Square	91.63558
Critical Value of t	2.11991
Least Significant Difference	8.2846

Means with the same letter are not significantly different.

t Grouping	Mean	N	den
A	63.637	12	1
B	50.440	12	2
B	46.187	12	3

APPENDIX B

Weather recorded during crop period (November 2010 to February 2011)

Average monthly weather data 2010 – 2011

Month	Av. Maximum (°C)	Av. Minimum (°C)	Av. Precipitation (mm)
November	30	19	0.0
December	29	18	0.0
January	28	17	0.0
February	32	17	0.0

Source: ww.wunderground.com/history/airport/VTCC/2011/2/1/MonthlyHistory.html

APPENDIX C

Test Results – Pesticide Residue Analytical Laboratory, Plant Protection Center, Royl Project Foundation 65 M.I Suthep Rd., T. Suthep, A. Muang, Chiang Mai 50200, Thailand (01/03/2011)

Issue Date : 03/03/2554

Report No : TR54/336

Page : 1 / 1

Test Report

Customer Name	MR. Shalendra		Address	Maejo University, Chiang Mai	
Kind of Sample	Cabbage		Center/Station	-	
Farmer Code	-		Farm Code	-	
Sampling Date	-	Receive Date	01/03/2011	Analysis Date	02/03/2011
Sampling Code	-	Sample weight	1 kg	Sample Code	82
Sampling Request Number	SPL -		Sampling Report Number	SPR -	

Residue analysis results issued by : Pesticide Residue Analytical Laboratory, Plant Protection Center, Royal Project Foundation
65 M.1 Suthep Rd., T.Suthep, A.Muang, Chiang Mai 50200, Thailand
Tel: +66(53)114234 Fax: +66(53)114235

Method of Analysis : In-house method based on J.AOAC. Int., 2007. Vol.90. No.2, p.485-520. (TE-CH-002)

Testing List : Abamectin

Sampling Technique : -

Sampling Location : -

Sampling Condition : ☐ Normal and appropriate ☐ Inappropriate *i.e*

Sample Appearance : ☒ Normal ☐ Abnormal *i.e.*

Sample Description : 2 heads of peeled cabbage in plastic bag

Deviation from the requirement : ☒ Normal and no deviation ☐ Deviation *i.e.*

ผลการวิเคราะห์:

Abamectin : Not detected

Organophosphate group : 1) Methamidophos 2) Mevinphos 3) Diazinon 4) Dicrotophos 5) Monocrotophos 6) Chlorpyrifos-methyl★ 7) Methidathion★ 8) Pirimiphos-methyl★ 9) Chlorpyrifos★ 10) Malathion★ 11) Fenitrothion★ 12) Quinalphos★ 13) Prothiophos★ 14) Profenophos★ 15) Ethion★ 16) Triazophos★ 17) Phosalone 18) Dichlorvos

Remark "★Accredited Test method Complying with ISO/IEC 17025:2005"

Analyst	Reviewed by	Approved by
(Thitaree Phannawong)	(Naruephon Wattanapap)	(Naruephon Wattanapap)
Position Technical Manager	Position Quality Manager	Position Quality Manager

Conclusion and Recommendation: ☐ Pass ☐ Reject ☒ Other :

Base on MRL of : ☐CODEX ☐EU ☐JAPAN ☐TAIWAN ☐USA ☐Thailand ☒ Other :

Other Opinion :

This report is certified on the sample tested only.

This report shall not be copied in part, except in full, without prior approval of the laboratory in written allowance.

FM-QP-25-01-020-R02 (15/01/54)P1/1

Issue Date : 03/03/2554

Report No : TR54/336

Page : 1 / 1

Test Report

Customer Name	MR. Shalendra		**Address**	Maejo University, Chiang Mai	
Kind of Sample	Cabbage		**Center/Station**	-	
Farmer Code	-		**Farm Code**	-	
Sampling Date	-	**Receive Date**	01/03/2011	**Analysis Date**	01/03/2011
Sampling Code	-	**Sample weight**	1 kg	**Sample Code**	S1
Sampling Request Number	SPL -		**Sampling Report Number**	SPR -	

Residue analysis results issued by : Pesticide Residue Analytical Laboratory, Plant Protection Center, Royal Project Foundation
65 M.1 Suthep Rd., T.Suthep, A.Muang, Chiang Mai 50200, Thailand
Tel: +66(53)114234 Fax: +66(53)114235

Method of Analysis : In-house method based on J.AOAC. Int., 2007. Vol.90. No.2, p.485-520. (TE-CH-002)

Testing List : Abamectin

Sampling Technique : -

Sampling Location : -

Sampling Condition : ☐ Normal and appropriate ☐ Inappropriate *i.e*

Sample Appearance : ☒ Normal ☐ Abnormal *i.e.*

Sample Description : 2 heads of peeled cabbage in plastic bag

Deviation from the requirement : ☒ Normal and no deviation ☐ Deviation *i.e.*

ผลการวิเคราะห์:

Abamectin : Not detected

Organophosphate group : 1) Methamidophos 2) Mevinphos 3) Diazinon 4) Dicrotophos 5) Monocrotophos 6) Chlorpyrifos-methyl★ 7) Methidathion★ 8) Pirimiphos-methyl★ 9) Chlorpyrifos★ 10) Malathion★ 11) Fenitrothion★ 12) Quinalphos★ 13) Profenophos★ 14) Profenophos★ 15) Ethion★ 16) Triazophos★ 17) Phosalone 18) Dichlorvos

Remark "★Accredited Test method Complying with ISO/IEC 17025:2005 "

Analyst	**Reviewed by**	**Approved by**.....
(Thitaree Phannawong)	(Naruephon Wattanapap)	(Naruephon Wattanapap)
Position Technical Manager	**Position** Quality Manager	**Position** Quality Manager

Conclusion and Recommendation: ☐ Pass ☐ Reject ☒ Other :

Base on MRL of : ☐CODEX ☐EU ☐JAPAN ☐TAIWAN ☐USA ☐Thailand ☒ Other :

Other Opinion :

APPENDIX D

Abstract of the research paper presented (oral presentation) in Annual Maejo Conference held on December 01, 2011 at Maejo University, Sansai, Chiang Mai, Thailand

Effects of Nitrogen and Plant Spacing on the Yield and Quality of Head Cabbage (*Brassica oleracea* L. var. *capitata*)

อิทธิพลของไนโตเจนและระยะปลูกที่มีผลต่อผลผลิตและคุณภาพของกะหล่ำปลี

Shalendra Prasad[1], Nippon Jayamangkala[2], Warunee Sirijornjaru[2], Jiraporn Inthasan[2]

[1]Graduate student, M.Sc. Horticulture, Maejo University, Chiang Mai, Thailand 50290

[2]Faculty of Agricultural Production, Maejo University, Chiang Mai, Thailand 50290

*Corresponding author: Shlndrprasad@yahoo.com

บทคัดย่อ

การทดลองอิทธิพลระดับปุ๋ยไนโตรเจน และระยะปลูกกะหล่ำปลีที่มีผลต่อผลผลิต และคุณภาพกะหล่ำปลีที่ทำการทดลองที่แปลงทดลองของสาขาพืชผัก มหาวิทยาลัยแม่โจ้ระหว่างพฤศจิกายน *2553*-กุมภาพันธ์ *2554* วางแผนการทดลองแบบ *Split plot in RCBD* โดยมี *Main plot* คือระดับของปุ๋ยไนโตรเจน *4* ระดับ คือ *0,14,16* และ *18* กิโลกรัมต่อไร่ และ *Sub plot* คือระยะปลูก *3* ระยะ คือ *50x30, 50x40,* และ *50x50* เซนติเมตร ผลการทดลองพบว่า เมื่อให้ปุ๋ยไนโตรเจน *14, 16*และ*18* กิโลกรัมต่อไร่ทำให้กะหล่ำปลีมีน้ำหนักผลผลิตแตกต่างจากการไม่ใส่ปุ๋ยไนโตรเจนอย่างมีนัยสำคัญ การใส่ปุ๋ยไนโตรเจน *18* กิโลกรัมต่อไร่ ทำให้กะหล่ำปลีมีน้ำหนักผลผลิตสูงที่สุดคือ *62.8* ตันต่อเฮกต้า ในขณะที่ไม่ใส่ปุ๋ยไนโตรเจน กะหล่ำปลีมีน้ำหนักผลผลิตต่ำที่สุดคือ *42.4* ตันต่อเฮกต้า การปลูกกะหล่ำปลีที่ระยะ *50x30* เซนติเมตรทำให้กะหล่ำปลีมีน้ำหนักผลผลิตสูงสุดคือ *63.6* ตันต่อเฮกต้า แต่ขนาดของกะหล่ำปลีมีขนาดเล็ก (0.8 กิโลกรัมต่อหัว) เหมาะสมกับการบริโภคภายในประเทศ ไม่เหมาะสมกับการส่งออก ส่วนการปลูกที่ระยะ *50x50* เซนติเมตร แม้ว่าจะให้ผลผลิตต่ำแต่ขนาดของกะหล่ำปลีมีขนาดใหญ่ (*1.2* กิโลกรัมต่อหัว)

Abstract

The effect of nitrogen and plant spacing on the yield and quality of head cabbage was conducted at Maejo University farm, in crop year 2010. Four nitrogen application levels; 0, 14, 16 and 18 kg per rai were main plot and three different plant spacings; 50x30, 50x40 and 50x50 cm were subplot. Split plot in RCBD was arranged in this experiment with 3 replications. The results revealed that nitrogen application 14, 16 and 18 kg per rai showed the high yield (tonnes/ha) when compared to no nitrogen application, with the highly different significant at $p < 0.01$. Nitrogen application level of 18 kg produced highest yield 62.8 tonnes per ha, while control (N = 0) showed the lowest yield 42.4 tonnes per ha. However, plant spacing of 50x30 cm produced the highest yield 63.6 tonnes per ha when compared to width plant spacing 50x50 cm, but head size of cabbages were smaller which was suitable for domestic consumption only, it could not be the standard size for export. No interaction analysis was observed in the measured parameters, but high nitrogen level with widest plant spacing showed high levels of nitrate accumulation in cabbages.

Keywords: head cabbage, nitrogen application level, plant spacing, head size, nitrate

APPENDIX E

Curriculum Vitae

CURRICULUM VITAE

Name	Mr. Shalendra Prasad	
Date of Birth	7th May, 1973	
Marital Status	Married	
Educational Background	1991-1993	Diploma in Tropical Agriculture (DTA) University of the South Pacific, Fiji
	2000-2002	Bachelor in Agriculture (B.Agr.) University of the South Pacific, Samoa
	2010-2012	Master of Science, Horticulture (MSc.Hort) Maejo University, Chiangmai, Thailand
Work Experience	1994-1999	Senior Research Assistant Research Division, Ministry of Agriculture, Fiji
	2000-2007	Agricultural Technical Officer Research Division, Ministry of Agriculture, Fiji
	2008	Research Officer (Hort.) Department of Agriculture, Ministry of Primary Industries, Fiji
Publication		Paper presented in Annual Maejo Conference held on 01-02 December, 2011 at Maejo University, Chiangmai, Thailand