

EXPERIMENTAL APPROACH FOR QUANTIFYING CROP WATER USE
AND POLLUTANT LOADING FROM AGRICULTURAL PLOT

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Specially dedicated to my beloved parents and friends for their blessings,
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ABSTRACT

Storm water runoff is the main contributor to non-point source (NPS) pollution in agricultural land. This issue is extremely important in tropical region due to its high intensity and frequent storms. The objectives of this study were to determine the crop coefficient of two vegetable crops – bittergourd (*Mormordica Charantia*) and chilli (*Capsicum Annuum*), investigate the mechanism of NPS pollutant transport and the influence of hydrologic regime on the pollutant loading. This study was conducted at the Modern Agriculture Centre in Kluang, Johor, from August 2013 to May 2014. A total of 86 rainfall events were recorded but only 52 storms had generated measurable runoff. Samples of runoff, soil water and groundwater were collected after every rainfall event and analysed for nutrient and sediment contents. Twenty-six reference evapotranspiration (ET_o) models which were classified into four different groups were employed and their performance was ranked based on eight different statistical test. Penman model provide the best result in estimating ET_o while the Schendel model tended to overestimate the observed pan ET. The limited parameters used in the temperature based group causes poor performance in predicting the ET_o values. Crop coefficient (K_c) curves for both crops were developed as the ratio of actual ET measured by minilysimeters to the ET values of the best model. The K_c values for the bittergourd were 0.58, 0.88 and 0.69 while for chili were 0.58, 0.95 and 0.73 for the initial, mid and end growth stages, respectively. More runoff event was observed for the bittergourd as its growing period coincided with the North-East Monsoon. The average runoff-rainfall ratio is less than one percent due to the high hydraulic conductivity of the site. The concentrations of nutrients and sediments were very high with maximum Nitrite (NO_2), Nitrate (NO_3), Ammoniacal-Nitrogen (NH_3-N), Phosphate (PO_4), Total Nitrogen (TN), Total Phosphorus (TP), Chemical Oxygen Demand (COD) and Total Suspended Solids (TSS) concentrations in the runoff were 0.385, 10, 4.2, 13.7, 27, 18, 190 and 15000 mg/l respectively. However, the calculated pollutant loading were low due to the remarkably small surface runoff volume. Soil water analysis at 15 and 60 cm soil depth shows a high Phosphorus (P) element leaching to the deeper depth even though P is less mobile. Nitrate concentration showed an increasing trend compared to other nutrients with a maximum of 1.7 mg/l at the end of the study period. The calibration and validation of the Root Zone Water Quality Model (RZWQM2) were carried out to model the leaching of NO_3 to the groundwater. The results of this study can be applied to formulate more reliable water management schemes based on the water requirement of the vegetable crops and providing new information for controlling NPS pollution loading from agricultural activities.

ABSTRAK

Air larian ribut adalah penyumbang utama kepada pencemaran punca bukan titik (NPS) di kawasan pertanian. Isu ini amat penting di rantau tropika kerana keamatan hujan yang tinggi dan berlaku dengan kerap. Objektif kajian ini adalah untuk menentukan pekali tanaman dua jenis sayuran iaitu – peria (*Momordica Charantia*) dan cili (*Capsicum Annuum*), mengkaji mekanisme pengangkutan bahan pencemar NPS dan pengaruh rejim hidrologi ke atas beban pencemar. Kajian ini telah dijalankan di Pusat Pertanian Moden, Kluang, Johor dari Ogos 2013 hingga Mei 2014. Sebanyak 86 kejadian ribut hujan telah direkodkan tetapi hanya 52 daripadanya menghasilkan air larian permukaan yang boleh disukat. Sampel air larian permukaan, air tanah dan air bawah tanah telah diambil selepas setiap kejadian ribut hujan dan dianalisis untuk kandungan nutrien dan sedimen. Dua puluh enam model sejatpeluhan rujukan (ET_o) yang telah diklasifikasikan kepada empat kumpulan telah diaplikasikan dan ditarafkan menggunakan lapan jenis ujian statistik. Model Penman menunjukkan prestasi terbaik dalam menganggarkan ET_o manakala model Schendel cenderung untuk terlebih anggar nilai ET_o . Bilangan parameter yang terhad dalam kumpulan model berdasarkan suhu menyebabkan prestasi yang lemah dalam meramalkan nilai ET_o . Lengkung pekali tanaman (K_c) untuk setiap sayuran telah dibina berdasarkan nisbah antara sejatpeluhan tanaman sebenar yang diukur menggunakan lisimeter mini dengan nilai ET_o dari model yang terbaik. Nilai K_c untuk peria adalah 0.58, 0.88 dan 0.69 manakala bagi cili adalah masing-masing 0.58, 0.95 dan 0.73 untuk peringkat awal, pertengahan dan akhir pertumbuhan tanaman. Lebih banyak kejadian air larian telah direkodkan semasa musim penanaman peria kerana ia berlaku semasa Monsun Timur Laut. Purata nisbah air larian-hujan adalah kurang daripada satu peratus disebabkan nilai kekondusian hidraulik tanah yang tinggi. Kepekatan nutrien dan sedimen di tapak kajian sangat tinggi dengan nilai maksimum bagi Nitrit (NO_2), Nitrat (NO_3), Ammonia-Nitrogen (NH_3-N), Fosfat (PO_4), Jumlah Nitrogen (TN), Jumlah Fosforus (TP), Kadar Permintaan Oksigen Kimia (COD) dan Jumlah Pepejal Terampai (TSS) dalam air larian masing-masing mencapai 0.385, 10, 4.2, 13.7, 27, 18, 190 dan 15000 mg/l. Air tanah pada kedalaman 15 dan 60 cm menunjukkan kepekatan unsur Fosforus (P) yang tinggi dan cenderung untuk meningkat dengan kedalaman walaupun pada hakikatnya P bersifat kurang bergerak. Kepekatan nitrat didapati meningkat sepanjang tempoh kajian berbanding nutrien lain dengan nilai maksimum 1.7 mg/l di akhir tempoh kajian. Kalibrasi dan validasi model kualiti air zon akar (RZWQM2) telah dijalankan untuk memodel larut lesap NO_3 ke air bawah tanah. Keputusan kajian ini boleh digunakan untuk membangunkan pengurusan air yang lebih sesuai berdasarkan keperluan air tanaman sayur-sayuran dan memberi maklumat baru untuk mengawal beban pencemaran NPS daripada aktiviti pertanian.

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LIST OF ABBREVIATIONS

ADD	-	Antecedent Dry Day
ARE	-	Absolute Relative Error
ASWC	-	Antecedent Soil Water Content
BMP	-	Best Management Practice
C	-	Carbon
C/N	-	Carbon/Nitrogen
COD	-	Chemical Oxygen Demand
CT	-	Conventional Tillage
DO	-	Dissolved Oxygen
DP	-	Dissolved Phosphorus
<i>E</i>	-	Evaporation
ER	-	Enrichment Ratio
ER _{oc}	-	Enrichment Ratio of organic carbon
ET	-	Evapotranspiration
ET _c	-	Crop Evapotranspiration
Et _o	-	Reference Evapotranspiration
FAO	-	Food and Agricultural Organization
FC	-	Field Capacity
<i>I</i>	-	Intensity
<i>K_c</i>	-	Crop Coefficient
<i>K_p</i>	-	Pan Coefficient
<i>K_{sat}</i>	-	Saturated Hydraulic Conductivity
LAI	-	Leaf Area Index
MSE	-	Mean Square Error
N	-	Nitrogen
NH ₃	-	Ammonia
NH ₃ -N	-	Ammoniacal-Nitrogen

NH ₄	-	Ammonium
NOF	-	Normalized Objective Function
NO ₂	-	Nitrite
NO ₃	-	Nitrate
NPS	-	Non Point Source
NSC	-	Nash Sutcliffe Coefficient
OC	-	Organic Carbon
P	-	Phosphorus
ρ_b	-	Soil bulk density
PO ₄	-	Phosphate
PP	-	Particulate Phosphorus
PS	-	Point Source
PSD	-	Particle Size Distribution
PWP	-	Permanent Wilting Point
R	-	Runoff
R ²	-	Coefficient of Determination
RE	-	Relative Error
<i>RH</i>	-	Relative Humidity
RMSE	-	Root mean square error
RR	-	Runoff Rainfall
R _s	-	Solar Radiation
RZWQM2	-	Root Zone Water Quality Model 2
ΔS	-	Soil water storage
SOC	-	Soil Organic Carbon
SOM	-	Soil Organic Matter
SWRC	-	Soil Water Retention Curve
<i>T</i>	-	Temperature
TN	-	Total Nitrogen
TP	-	Total Phosphorus
TS	-	Terrace Structure
TSS	-	Total Suspended Solid
<i>U</i>	-	Wind Speed

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CHAPTER 1

INTRODUCTION

1.1 Background Information

Human have benefited a lot from nature for a long time. Sadly, the relationship between us humans and nature are not symbiotic where most of human activities were done without thinking about their damage on nature due to pollution. Pollution can be divided into two; point source (PS) and non-point source (NPS) pollution. A point source refers to pollution from a known source at an identifiable point (e.g.; pollutants and wastewater from industrial, commercial and domestic areas) while non-point source pollution originates from multiple discharge or diffuse points where it mostly occur during rain storm (Choi et al., 2011). Besides rainstorm, water that is used in human activities like irrigation also contributes in transporting non-point source pollutants throughout a large area. In comparison, monitoring and controlling of nonpoint source pollution is more difficult as its pollutants source are difficult to trace and depends on the unpredictable meteorological events and geographic condition. Studies in the United States, Japan and other countries had shown that Agricultural non-point source (ANPS) pollution has become a major concern nowadays (Carpenter et al., 1998; Zhang et al., 2009b).

Generally, non-point source pollution has the following characteristics (Novotny and Olem, 1994).

- i) The sources of pollution are wide spread; pollutants such as suspended solids, nutrients, and toxic compounds are discharged into

the receiving waters in diffuse manner and are strongly influenced by the storm characteristics.

- ii) The pollutants generation processes usually occur over the entire land surface area. Before pollutants enter a water body, there are transport processes that occur over a wide region, accompanied by dissolution, dispersion and infiltration.
- iii) Non-point source pollutants are usually discharged at unknown instants of time into the water system with uncertain values of concentration. These factors are influenced by unexpected natural conditions, or the accidental discharge of pollutants.
- iv) The extent of non-point source pollution is determined by many factors which are related to climatic events, geographic and geologic features, and may show large temporal and spatial variations.

Examples of ANPS pollutants include fertilizer, pesticides, sediment, bacteria from feedlot, oil spill and nutrients. These pollutants can affect the environmental quality and public health badly, due to eutrophication of lakes and streams, soil contamination by heavy metals and the accumulation of pesticide residues in food (Shen et al., 2012). In an agricultural catchment, runoff that is produced during rainstorm will carry away pollutants which is natural or man-made and deposit it into water bodies like lake, river, wetlands and later contaminating them causing the water unsafe for drinking purpose (Yamada, 2007). NPS pollutants do not only limited to surface water bodies but also can leach into the ground and contaminate the ground water (Braskerud, 2002b, 2002a).

Each storm event is unique and depends on various factors such as storm duration and intensity, antecedent meteorological conditions (air patterns, humidity) and catchment characteristics (Parn et al., 2012). Land development practices may also influence the amount and the characteristics of runoff-flow. In addition, rainfall pattern diversity causes different transport mechanism of pollutants over a catchment

surface and the rate of pollutant transport also varies with the flow rate and different concentration in time can be expected. This becomes a challenge to accurately characterize the quality of the runoff and determine the level of pollution in agricultural land.

Compared to the point source pollution, more efforts and investments may be required to deal with NPS pollution due to the unique characteristics of storm and runoff flow. The discharges of storm water are periodic, causing different types of effects than the better regulated continuous point source discharges (Emili and Greene, 2013). Besides, yearly rainfall amounts and distribution may change from time to time. Storm water also causes episodic disturbances in aquatic ecosystems (Minshall, 1988) whose patterns of occurrence are chaotic in nature (Pool, 1989) and the characteristics are unique to each event. Thus, quantification of stormwater pollutant loadings is difficult because of the wide variability of stormwater quality.

Crop water use is a function of evaporation (E) and transpiration (T) that fluctuates daily. Allen et al. (1998) provides definition of evapotranspiration (ET) and reference evapotranspiration (ET_0). ET is defined as the sum of evaporation from water/soil surfaces and the amount of water transpired by plants. ET_0 is defined as evapotranspiration from an extensive surface of green grass of uniform height (0.08-0.15 m), an albedo of 0.23, fixed canopy resistance (70 sm^{-1}), actively growing, completely shading the ground, and not short of water (Allen et al., 1998). There are many components that affect ET_0 , which include weather variables like solar radiation, air temperature, relative humidity (RH), and wind speed; crop factors such as type of vegetation, crop density and the growth stage; and other conditions such as soil type, salinity, fertility, cultivation level, crop disease, and pests (Allen et al., 1998). ET is one of the most difficult components to be determined in the water balance compared to other components like precipitation or irrigation (Fisher et al., 2005; Xu and Singh, 2005).

1.2 Problem Statement

Sustainable land and reliable food production is important for humanity. Agricultural practices determine the food production level and the state of the global environment. About half of global usable land is already in pastoral or intensive agriculture. Global cereal production has increased for the past decades mainly due to greater inputs of fertilizer, water and pesticides and other technologies from the 'Green Revolution' (Tilman et al., 2002). In the 1950s, agricultural sectors in Malaysia mainly focused on self-sufficiency food. However, since the 1980s, this strategy has changed toward export-oriented agricultural products.

Besides causing the loss of natural ecosystems, agriculture activities also contribute to considerable amounts of nitrogen and phosphorus that are detrimental to the terrestrial ecosystems. Parris (2011) stated that agricultural nonpoint source pollution has become a major concern nowadays as it is able to degrade water quality and has therefore received increasing attention around the globe including in developing countries. According to Yang et al. (2009), 30 to 50 % of surface water is influenced by non-point source pollution.

To increase production of vegetables and fruits, farmers nowadays tend to increase the input of fertilizer more than the required quantity. Over time, agricultural land is getting less fertile and many farmers resort to applying more chemical fertilizers to compensate the declining fertility. If crops are not growing well as expected, they often blame the quality of the chemical fertilizers and use more fertilizers. This fertilizer contains primary nutrients like nitrogen and phosphorus that causes eutrophication and affecting the aquatic habitat (Chambers et al., 2011). Lakes affected by eutrophication are not suitable to be used as drinking water due to its deteriorating water quality besides increasing the cost of water treatment process. In Malaysia, large amount of nutrients are required due to low soil fertility and to achieve high crop yield (Ann, 2012; Goh et al., 2012), therefore runoff with high nutrients contents cannot be avoided.

Sembrong Dam was originally constructed for flood control in the Kluang district but later the water is used for water supply by Syarikat Air Johor (SAJ). Water from Sembrong Dam is distributed to residents in Kluang and Batu Pahat area for domestic use. Water supplied to consumers must be of high quality, as measured by the Water Quality Index (WQI). A large part of the catchment area is under agricultural activities such as oil palm plantation, vegetable farm and orchard (Nelson, 2015). These activities also contribute to lake pollution by the fertilizers and pesticides carried to the river through surface runoff (Baharim 2015). Baharim (2015) also reported that the P level at the dam were more than 90% compared to the normal 70-80% in the Carlson Trophic Index. Livestock manure from fertilizing activities leads to high nutrient content in the lake.

In addition, the physical condition of the lake may be affected due to reduction in dissolved oxygen (DO) by algae and aquatic plants. Nutrient input to the lake causes increase of algae bloom. Later on, this can lead to eutrophication problem which changes the water to green (Baharim, 2015). While this algae can be killed during water treatment process, it will cost more than usual. Due to this, it is crucial to control loading of pollutants that is transferred by overland flow before reaching the nearest waterbody.



Figure 1.1 Greenish lake water due to eutrophication

Agriculture activities also contribute to land degradation through soil erosion from an agricultural land to streams which reduced the fertility of the soil as most nutrients and organic matter are contained at the topsoil (Sharma et al., 2004). Study of soil loss due to surface runoff is very important to determine erosion hotspot areas which are very widespread in humid tropical regions such as Malaysia (Toum et al., 2005). In an attempt to restore the soil to its original composition, more fertilizers and organic matter must be added. Soil erosion refers to the process where soil particles are removed from earth surface by natural process which will later be transported by wind or water to different place to be deposited. Erosion is the largest portion of NPS pollution in the tropical region as it causes sedimentation in lakes and reservoir, increase flood frequency and reduces storage capacity of lake. Sediment refers to eroded soil or suspended solids due to erosion process or surface runoff on an agricultural land, stream banks and highly disturbed area.

In addition to runoff process, pollutants can also be leached far below the ground level till the groundwater. Another motivation of this study is to know how fast different types of pollutants travel below ground surface. Agricultural land with a shallow groundwater level can cause this pollutants to enter the nearest waterbody by baseflow.

Water use in agriculture is also an area of interest in determining the water consumption of plants; therefore a water budget analysis is required to account for the movement and transformation of water in study site. Despite the importance of ET in hydrologic studies, spatial field-scale and short timescale variability remain poorly quantified, and thus this topic deserving further investigation.

Quantification of ET is crucial for sustainable water resources management in the hydrological, agricultural, and environmental studies. There are numerous models exist to estimate the ET_0 , but these models give inconsistent values due to their differences in modeling assumptions and input data requirements, or because the models have been developed for specific areas (Lu et al., 2005; Xu and Singh, 2005). Among these models, the FAO56 Penman-Monteith model is considered to be the best approach for estimating ET_0 and for the determination of crop coefficient

because of its good approximation to lysimeter observations (Droogers and Allen, 2002; Xu and Singh, 2002; Popova et al., 2006). However, the FAO56 Penman-Monteith model requires many weather variables which can potentially introduce measurement and/or computational errors and cause cumulative errors in the calculated ET_o (Rahimikhoob et al., 2012). Due to this, other models that require less parameter should be considered for evaluation. Even though certain models such as Blaney-Criddle, Hargreaves, Makkink, Priestley Taylor and Turc, are developed under different weather variables, the models have been proven useful when applied at different climate regions (Kashyap and Panda, 2001; Xu and Singh, 2001; Trajkovic, 2007). Therefore, multiple ET_o evaluation study for tropical regions is urgently required as there is not much of researches involving ET_o models in the tropic region besides the Penman Monteith.

Crop water use or water requirements are determined by multiplying ET_o with crop coefficient, K_c . It is useful to determine the water requirement of crops according to their growth stage and environmental factors. The K_c value is sensitive and depends on several aspects such as type of crop, weather variables, canopy cover density, growth stage, soil moisture and agricultural operations (Allen et al., 1998). Previous studies have found that K_c for the same crop may vary from region to region depending on environmental factors such as climate and soil evaporation. Even though Allen et al. (1998) have compiled a list of K_c of various crops under different climates, K_c for a crop still has to be determined regionally as it may vary with factors like types of crop, growing stage, soil moisture, climate and agronomic techniques (Doorenbos and Pruitt, 1977; Ko et al., 2009; Piccinni et al., 2009). In addition, some authors have reported differences between published and locally developed K_c (Tyagi et al., 2000; Kashyap and Panda, 2001). Due to this, more studies on determining different types of crop K_c at different climates should be conducted as it may help modelers and water resource engineers to provide more reliable water management schemes. Bittergourd (*Momordica Charantia*) and chili (*Capsicum Annuum*) are some of the most popular vegetables due to its nutrient and medicinal properties that grow in tropical areas such as the Amazon, east Africa, Asia, and the Caribbean. The total requirement of chili in Malaysia reached up to 50000 tonnes per year (harvested area = 2986 ha). Due to insufficient domestic

production, Malaysia need to import chili from neighbouring countries like Indonesia (A'fifah et al., 2015). Bittergourd has a long history of medicinal use especially in diabetes treatment, diarrhea, skin fungal infections and hypertension (Crisan et al., 2009). These vegetables are selected since there is lack of study on their crop water use in south-east Asia region.

1.3 Objectives of Study

The main goal of this study is to provide the quality and quantity of pollutant and their transport mechanism. The results of this study would allow the authorities to have a better understanding of the pollutant sources from different agricultural land use. More importantly the findings are useful to help the authorities in designing agricultural runoff pollution control measures.

Specifically these study objectives are:

- i) To determine crop water use of *Momordica Charantia* and *Capsicum Annuum* at plot level
- ii) To investigate concentration and loading of nutrient and sediments from plot planted with vegetables from Objective 1.
- iii) To quantify pollutant leaching rate at agricultural farm and parameters of RZWQM2 model for the nitrate leaching study at agricultural plot

1.4 Scope of Study

Like in other studies, this particular study has its own limitations, both in scope and methodology. To achieve the above objectives, the following tasks were carried out:

- Selection of the study site preferably must be located in an agricultural area. The site must be accessible to facilitate data collection.
- The ET modelling use 26 different ET_o models from four different groups classified based on its weather parameter requirement. The performance of the models was evaluated using Class A pan evaporation data from the Kluang weather station. Eight statistical tests were used to assess and rank the accuracy of these 26 models. The ET values from the best ET_o model of each group were then modeled with weather variables using multiple regression technique.
- Usage of minilysimeters to determine the ET_c as actual ET depends on soil moisture. The obtained ET_c with the ET_o is used to determine the crop coefficient of both chili and bittergourd. The chili and bittergourd were not planted simultaneously to accommodate the farm management planting schedule at that time. A control plot is not necessary as the study compare the influence of two different crops rather than looking at different levels of treatment.
- Establishment of an experimental plot (7.1 x 12.2 m) at the study site. The study site is selected based on its location which is far from human disturbance. A tipping bucket flow gauge (model TB1L) was installed at the lower end of the plot to measure water flow and collect runoff during a storm event.
- The study focuses on sediment and nutrient (N & P) transport in runoff, soil water and groundwater. All water samples is collected after a storm event and tested at the Environmental laboratory of UTM. All laboratory works for

water quality conforms with Standard Methods for the examination of water and wastewater (APHA, 2005) for Nitrate (NO_3), Nitrite (NO_2), Ammoniacal Nitrogen ($\text{NH}_3\text{-N}$), Total Nitrogen (TN), Phosphate (PO_4), Total Phosphorus (TP), Chemical Oxygen Demand (COD) and Total Suspended Solid (TSS).

- RZWQM2 modelling is used in this study to calibrate and validate NO_3 movement in soil water to groundwater due to its high mobility in soil water.

1.5 Significance of Study

The findings of this study are useful for proposing crop water use for crop in Malaysian climate and designing storm water control facilities, by identifying the concentrations and loading of storm water runoff and leaching at vegetable planting land uses in agricultural catchment. The results also help the authorities to improve the strategies of the agricultural runoff and leaching management program.

The specific benefits are as follows:

- i) Providing more reliable water management schemes for vegetable crops to avoid under / over irrigation.
- ii) Provides new information/data for controlling NPS pollution from agricultural activities.
- iii) Enhanced understanding of pollutant transport processes in agricultural area by different types of crop.

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