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Weed Control Decision Support System Based on Precision Agriculture Approach

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Abstract

Herbicides have been widely used for weed control in modern agriculture. However the use of herbicides is potentialy introducing negative impact to the environment due to excessive use of herbicides. Based on precision agriculture principles, unique and precise treatment of herbicide supply for a particular area for crop production must be performed. The objective of this research is to develop a decision support system (DSS) for schedulling of weed spraying and for selecting the proper nozzle size of the sprayers that introduce minimum negative impact to the environment. The main set of data required for our proposed system includes the set of 10 years weather data series acquired from remote sensing (NOAA and TRMM) and a set of vegetation index from MODIS EVI. The weather data set is utilized to determine the planting time period of paddy crop and to determine the proper size of the sprayers for weed spraying. Our DSS prototype has been implemented and tested with real data set in Jonggol district, West Java, Indonesia. The implementation, testing results, and future enhancement of our system are discussed in this paper.

Keywords: *DSS, precision agriculture, weed control, herbicides, spray drift, weather pattern, temporal data*

1. Introduction

Weeds are a serious problem for agricultural crop. They rob main crops of sunlight, water and nutrient causing production losses both in quantity and quality. Losses due to weed were for wheat (9.8%), rice (10.8%), maize (13%), sorghum (17.8%), potatoes (4%) and groundnut (11.8%). Even, an uncontrolled weed can decrease yield until 20-80%. Herbicides are the dominant tool used for weed control in modern agriculture [1]-[4].

Although herbicide has positive benefit in killing the target weeds, it potentialy becomes negative impact if some remains in the air and drift. Spray drift from herbicide can cause crop protection chemicals to be deposited in undesirable areas [5]. It has serious consequences such as damage to sensitive adjoining crops, damage to susceptible off-target areas, environmental contamination, illegal herbicide residues, lower yield results, and health risks to animals and people [6]-[10].

Spray drift continues to be a major problem in applying herbicides. Factors that cause drift are unsuitable weather conditions and sprayer setup [11]. Drift can happen due to unsuitable weather. It potentially occurred every time when sprayer turned on. The knowledge of weather condition will help farmer and decision maker to decide the appropriate technology and method for eradicating weed, plan, and effectively execute spray applications to avoid spray drift and other potential waste.

The progress of information technology has been applied widely in agriculture such as precision agriculture [12],[13]. A weed control method in precision agriculture using multi-agents based has been developed in [1]. The method was a supervisory system to determine technology and liquid applicator capacity and controlling agents. That system has two functions, consultation function before spraying (off farm) and spray controlling by multi-intelligent agents (on farm) which applied for groundnut farming. Decision making method was considering influence factors on weed control activity such as crop, weed, herbicide, weather, application

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time and sprayer technology. While agents were for: image acquisition, filtering, crop detection, determination weed density, and determination herbicide dosage. The weather conditions both spatially and temporally have not studied more in previous research. Relationship with this research is the system built in [1] needs to be improved in knowledge that related with weather along with spray scheduling to make a decision that environment friendly. Spray schedule of a crop studied through vegetation index derived from MODIS satellite [14].

The spatial and temporal variability weather conditions are important sources for agricultural activities such spray application. Integration meteorological satellite with Numerical Weather Prediction (NWP) product is promising in find timely weather variables as input for decision making to resolve problems in spray application especially for area which sparse coverage of weather stations [15],[16]. However, the availability of data in real-time is still difficult to achieve. The Tropical Rainfall Measuring Mission (TRMM) data is capable of providing daily rainfall. NWP products from NCEP/NOAA such as 2 m temperature, wind, and relative humidity (RH) are used as other input. Moreover Data from experience could be used for scheduling and become decision support for preparing tools and machinery before spray application conducted [14].

The objective of this research is to develop a decision support system (DSS) for schedulling of weed spraying and for selecting the proper nozzle size of the sprayers that introduce minimum negative impact to the environment. To optimize spray scheduling, we look for suitable weather condition during spray application time. Spray application time is identified through crop phenology which derived by MODIS EVI.

2. Method

The research was conducted by using remote sensing approach. It is useful to give a better understanding about the earth's phenomenon [17],[18]. In this study, remote sensing used to study index of vegetation and weather condition. Crop phenology which identified through vegetation index [19] used to know spray application time. Research conducted on paddy plantation. Remote sensing technology has capability to recognize the phases of plant growth through study of vegetation indices from planting to harvest [20]. The growth phase of the study focused on the planting phase. Planting phase used to estimate the interval time of pre planting to post emergence. Then, that interval considered as the time for spraying. Weather variables during spraying time are studied in order to optimize the weed control and minimize negative impact to the environment.

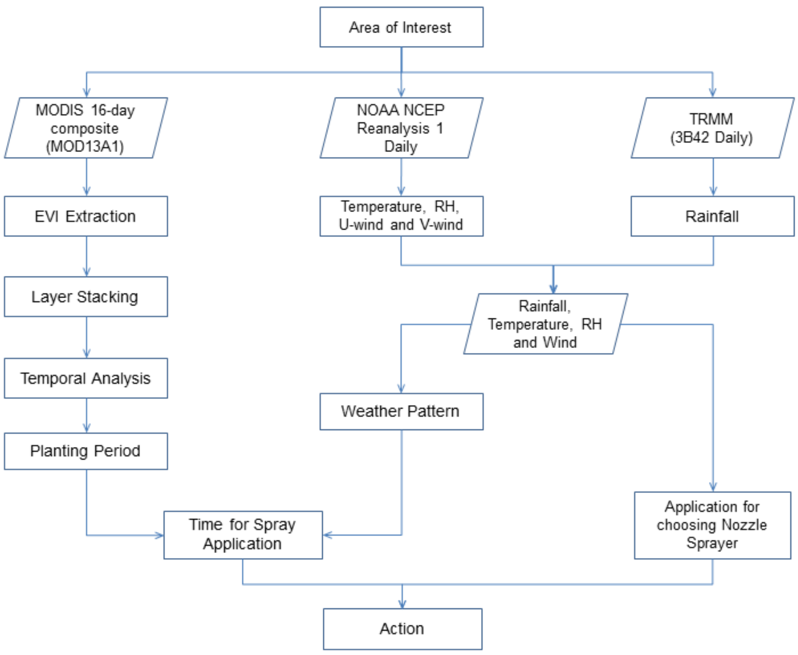


Figure 1. General framework of this study

2.1. Study Location

This study is an examination of crop and weather conditions in rice field which located in Jonggol, Bogor, West Java, Indonesia (upper left corner: 6°25'S 106°7'E; lower right corner 6°36'S 107°8'E) and has an area of 135.65 km^2 (Figure 2). About 64.3 % of Jonggol is agricultural area, with land use as follows: paddy field, mixed gardens, and plantations. Paddy field covers about 51.3 km^2 or 37.8 % of the total area. According [21], Jonggol is the largest producer of rice every year in Bogor, so it is often referred to as the central of rice in Bogor district. We were not studied whole area of Jonggol. We determined several paddy rice fields for samples which have area about > 500 m^2. It was related with the highest spatial resolution of each satellite data. These fields were presented by several pixels of MODIS image while all pixels considered as one grid coverage of NOAA and TRMM data.

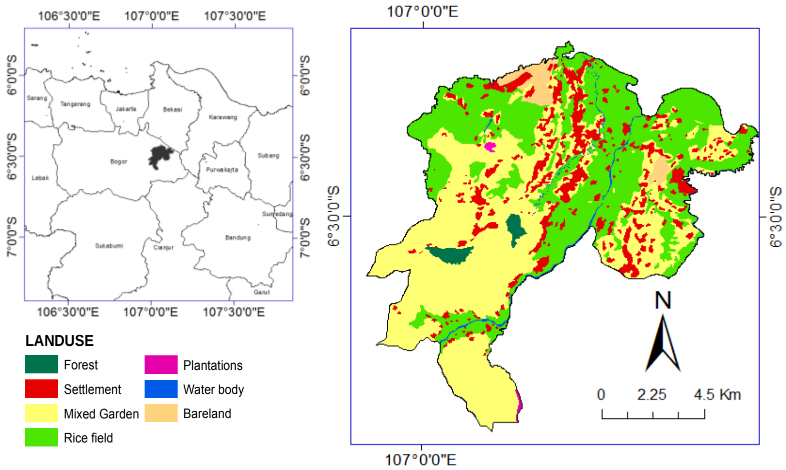


Figure 2. Location of study, Jonggol district, West Java, Indonesia.

2.2. Satellite Data

2.2.1. MODIS EVI

The MODIS product used in this study is the Vegetation Indices (VI) Composite 16-day Global 500 m SIN Grid V005 or MOD13A1 product, which provided the needed vegetation phenology data. In addition, the product had already been systematically corrected for the effects of gaseous and aerosol scattering. The MODIS EVI is embedded in the MOD13A1 product. The MODIS Land Discipline Group (MODLAND 2010) developed the EVI for use with MODIS data following this equation:

$$\mathrm{EVI} = \mathrm{G}\,\frac{\rho^*_{nir} - \rho^*_{red}}{\rho^*_{nir} + C_1\rho^*_{red} - C_2\rho^*_{blue} + L}\,(1 + L) \quad (1)$$

where, ρ^*_{nir}, ρ^*_{red} and ρ^*_{blue} are the remote sensing reflectances in the near-infrared, red and blue, respectively, L is a soil adjustment factor and C_1 and C_2 describe the use of the blue band in correction of the red band for atmospheric aerosol scattering. The coefficients, C_1, C_2 and L, are empirically determined as 6.0, 7.5 and 1.0, respectively. G is a gain factor set to 2.5. The EVI data were developed in the above form (Equation (1)) in order to optimize the vegetation signal with improved sensitivity in high biomass regions. The EVI also minimizes atmospheric influences with the 'aerosol resistance' term which uses the blue band to correct aerosols influence in band red [22].

In this study we used the MODIS EVI data sets which were acquired from January 2010 to December 2012 and captured 69 time series with the interval time 16 days. The study area is covered by only one MODIS tile: h28v09. MODIS EVI data were extracted from the MODIS VI product (MOD13A1) using the MODIS Reprojection Tool (USGS LP DAAC 2009b) and the selected output format was GeoTIFF and coordinate system was geographic coordinate systems on datum World Geodetic System of 1984.

2.2.2. NOAA NCEP/NCAR Reanalysis 1

Weather data obtained from National Oceanic & Atmospheric Administration (NOAA) that issued by The Mission of the ESRL Physical Sciences Division (PSD). The NCEP/NCAR Reanalysis 1 project is using a state-of-the-art analysis/forecast system to perform data assimilation using past data from 1948 to the present. It has temporal resolution of 4-times daily, daily and monthly values for 1948/01/01 to present which has grid global of spatial resolution. Weather data used in this study were as follows: air temperature, relative humidity, u-wind and v-wind. Each variable has near the surface (.sig 995 level) dataset on a $2.5^{o} \times 2.5^{o}$ grid in daily resolution. The product (.sig 995 level), air temperature, relative humidity and wind are above surface exactly 2 m, 2 m and 10 m, respectively. For this study we used four kinds of NCEP/NCAR Reanalysis 1 of data sets which were acquired from January 2003 to December 2012 and collected 3650 time series for each parameter with daily interval time.

2.2.3. TRMM 3B42

The rainfall product from TRMM satellite is combination of the Precipitation Radar (PR), TRMM Microwave Image (TMI), and Visible and Infrared Scanner (VIRS) [23]. TRMM 3B42 daily data is the data level 3 the results of data processing 1B01, 2A12, 3B31, 3A44 and Global precipitation index (GPI). The final 3B42 precipitation (in mm/hr) estimates have a 3-hourly temporal resolution and a 0.25^{o} x 0.25^{o} spatial resolution. Spatial coverage extends from 50 degrees south to 50 degrees north latitude. The daily accumulated (beginning at 00Z and ending at 21Z; unit: mm) rainfall product is derived from this 3-hourly product. The data are stored in flat binary. In this study we used this product which were acquired from January 2003 to December 2012 and collected 3650 time series with daily interval time.

2.3. Data Processing

MODIS EVI data obtained in GeoTIFF format. EVI was extracted using MODIS conversion toolkit or MODIS reprojection tool that provided by NASA. MODIS has systematically corrected but not geometrically corrected so that necessary rectified manually. The rectification was done use the corrected beach vector [24]. While the weather data obtained in netCDF format and geometrically corrected. Climate data operator (cdo) used to manipulate netCDF data format. For example, it uses to compute wind speed and direction which derived from northern and southern wind. The next step was layer stacking. The MODIS and weather data were sequentially stacked to produce the time-series data set and then clipped to cover study area composite period. The stacked data were evaluated to get temporal pattern from the time series data [19].

2.4. Data Analysis

Several points of study area were taken that represented location of paddy field. The EVI of these points were analyzed time-series every 16 day during three years. Weather condition of a pixel weather data where points located was considered as weather condition of all point of study area because it has coarse spatial resolution. Weather condition was analyzed time-series daily during 10 years observation.

2.5. Estimation of Weed Control Time

Normally, weed control in precision agriculture is performed twice, i.e. pre-planting and post-emergence [1]. These time could be estimated when the planting time known. Rice phenology from planting to harvesting represented trough EVI, the planting time used as reference to estimate time for weed control. Daily weather condition during pre-planting to post emergence interval was analyzed. Pre-planting estimated a month before planting month and post-emergence estimated a month after planting month. Then the interval from pre-harvest to post-emergence considered as weed control time.

2.6. Development Application to Determine Nozzle Sprayer

This application was developed with objective to determine nozzle size for sprayer. It expected could minimize drift on weed control. This simple application could be combined with

agent of weed control system [1] to improve precision of spray application. The rules (IF – THEN) to decide which nozzle sprayer were acquired from previous researches [1, 25] which interpreted into decision tree. This application was designed and developed using system development life cycle (SDLC) [26]. SDLC is the traditional methodology used to develop, maintain, and replace information system. The different phases of the SDLC are: investigation, analysis, design, implementation and maintenance.
Some rules of decision-making based on weather conditions were [1]:
1) Rules for parameter of Wind Speed (km/hr)
   - If WS < 2, then do not spray
   - If 2 ≤ WS ≤ 3, then spraying with air assists, with a medium droplet size
   - If 4 ≤ WS ≤ 6, then use a fine droplet size
   - If 7 ≤ WS ≤ 10, then use a medium droplet size
   - If 11 ≤ WS ≤ 14, then use a coarse droplet size
   - If 15 ≤ WS ≤ 20, then spraying with air assists, with coarse droplet size
   - If WS > 20, then do not spray
2) Rules for parameter of Air Temperature (˚C)
   - If T < 15, then spraying with droplets fine
   - If 15 ≤ T < 20, then spraying with droplet medium
   - If 20 ≤ T < 25, then spraying with coarse droplets
   - If T > 25, then spraying with air assists, with coarse droplet
3) Rules for parameter of Relative Humidity (%)
   - If RH < 40, then spraying with air assists, with coarse droplet size
   - If 40 ≤ RH < 60, then spraying with medium droplet
   - If 60 ≤ RH < 80, then spraying with fine droplets
   - If RH > 80, then spraying with air assists, with medium droplet size

3. Results and Discussion

Weed control method was developed by utilization of weather data that obtained from remote sensing. It became essential for area which sparse coverage of meteorology stations and requires a long time series data. Time series data in previous years used to optimize spray scheduling by looking for suitable weather condition and to prepare the spraying machinery and equipment for weed control that minimize the negative impact of herbicides to the environment.

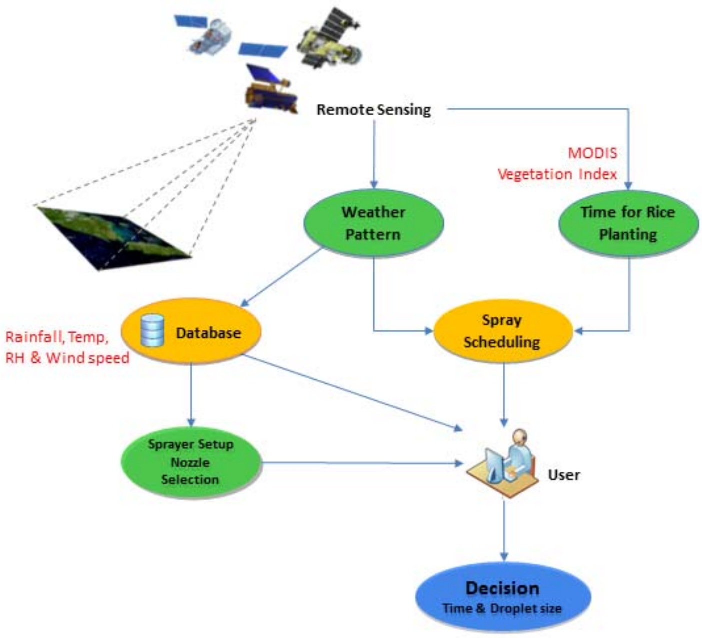


Figure 3. Utilization of weather data for weed control

3.1. Spray Application Time

In precision farming, weed control is done two times i.e. pre-planting and post-emergence. To know these times, time for planting is identified first. Paddy planting time identified through multi-temporal analysis of vegetation index. Figure 4 showed pattern of enhanced vegetation index (EVI) of paddy field in study area which fluctuated during three years data observation. EVI clearly shows the annual vegetation growth cycle, representing intensive cropping with multiple harvests. The EVI pattern of paddy has an almost symmetrical bell shape [14]. The vegetative growth stage correlated with the increasing EVI value until it reaches the maximum. The maximum of EVI value shows very green color from paddy leafs. It happens in heading/panicle stage [20].

Figure 4 show that the cropping cycle of paddy started about from April to July, October to February, respectively for cycle 1 and cycle 2. The time for planting considered as time where cropping cycle started. The planting times were April and October. These times were not general time for planting, but these times just for the points of study area [14]. In real condition the planting time may earlier or later than these points. As mentioned in previous section, planting phase is used to estimate the time interval of pre-planting to post-emergence. Then, that interval is considered as the time for spraying. Here the spraying time approximated one month before and after these months i.e. spraying time are March to May and September to November for cycle 1 and cycle 2 respectifely.

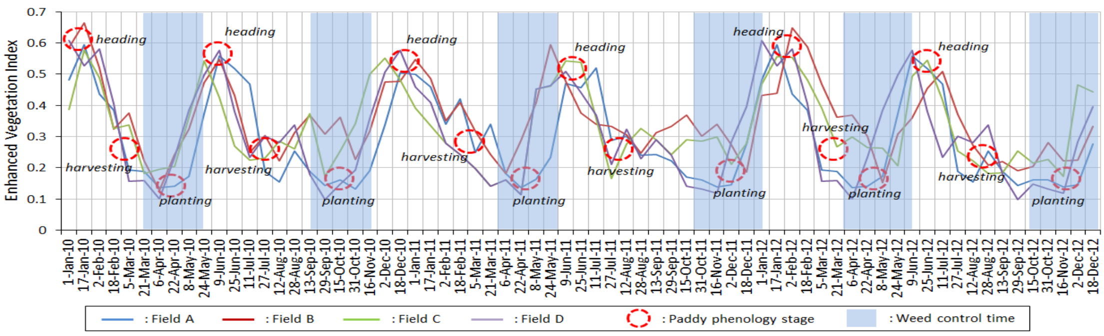


Figure 4. Weed control time which estimated from planting time through vegetation index

3.2. Weather Pattern

Figure 5 shows weather pattern in Jonggol during ten years. This information is used to facilitate farmer or decision maker to know the weather condition before applying herbicide to protect the crop. By this information, problems on weed control such as drift and run-off can be minimized by preparing machinery and sprayer earlier before spraying time. Every parameter have own characteristic and generally in same fluctuated pattern form. Dry and wet season are clearly seen in weather pattern (Figure 5) which affected by monsoon.

Generally, during ten years rainfall is high in year-end to early year while low in in mid-year. Wind speed is fluctuates. Wind is high in year-end to January every year about more than 10 km/s. For ten years, minimum and maximum temperatures are 23.5°C and 30°C. Relative humidity decreased when air temperature increase. It is about 65 – 95%, high in year-end to early year, and lowers in middle year. Western wind of seasonal monsoon during period December to January takes abundant water vapor so rainfall in that time tends to high.

Farmer or decision maker can use past weather data to find out the optimal time for scheduling, preparing machinery and sprayer. Optimal week for spraying determine from interval time for spraying both in crop cycle 1 and crop cycle 2. According to [1], ideal condition of wind for spraying is 3.2 – 9.6 km/h and wind more than 9.6 km/h can cause drift. Sometime sprayer need air assist technology by adding pressure to help herbicide drop to target weed. In [1], do not spray when the relative humidity less than 40% and temperatures above 25°C in order to reduce drift caused by temperature inversions or evaporation, also increases the target deposition and coverage. In study area the temperature can be higher and lower than 25°C but humidity more than 65%.

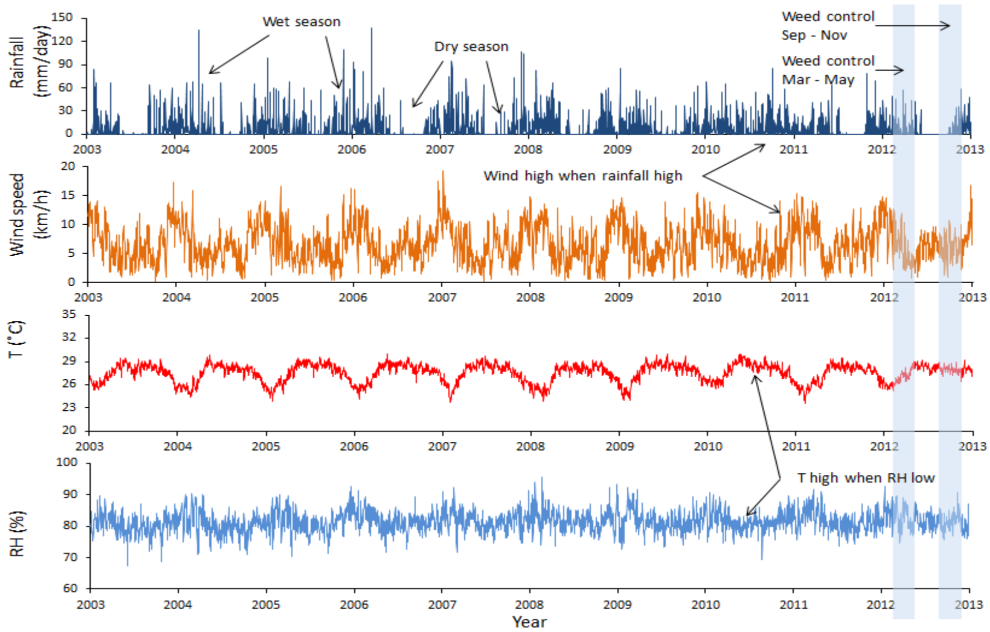


Figure 5. Weather pattern of study area and its utilization for characterizing weather condition during spray duration

The optimum week for spraying can be determined by using criteria that can minimize spray drift [1]. For example (Figure 6), weed control can be conducted in pre-planting or after planting and post-emergence. Spray application performed after planting until post-emergence (April – May). That time included to critical period of weed competition. It is about 40 days after planting.

Spraying herbicide for paddy is appropriate performed whenever after planting. It is due to in general time before planting weed control is conducted by plowing. Remaining biomass, soil and weed are mixed. Weed on the top soil moved to lower layer of soil. Weed is hard to grow even weed will be died because they cannot continue the photosynthesis process.

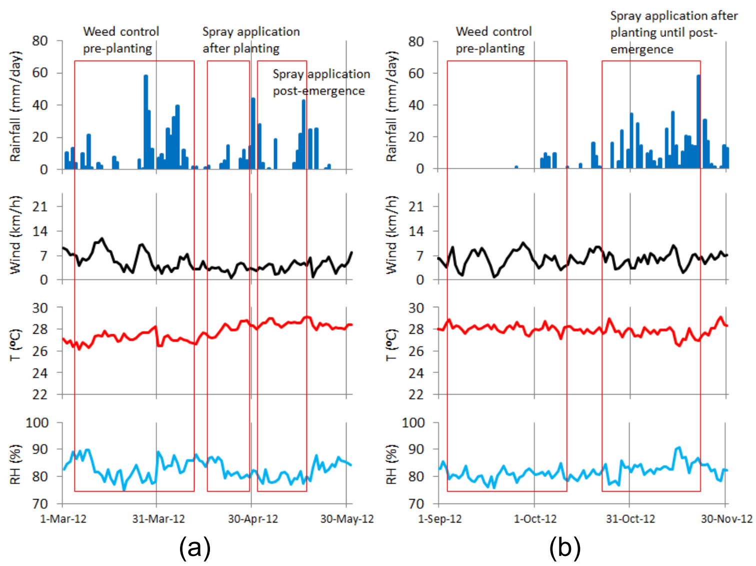
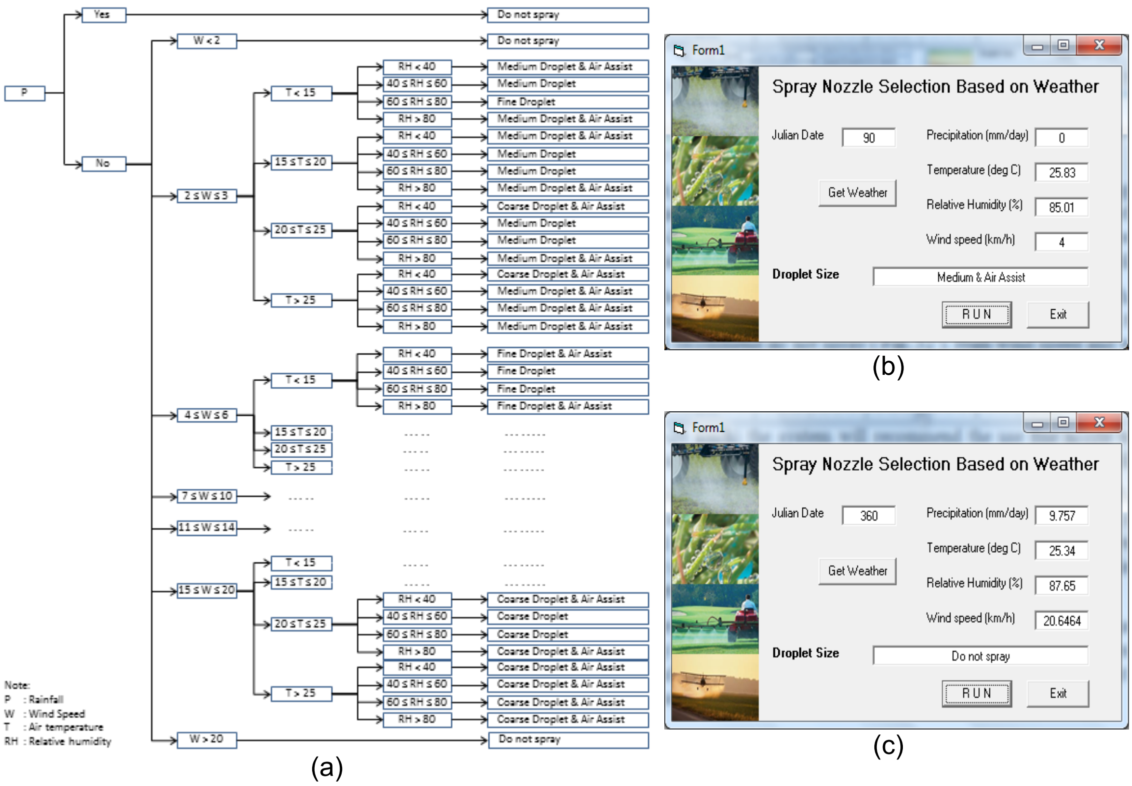


Figure 6. Weather condition during weed control interval in both paddy planting cycle 1 period March – May (a) and paddy planting cycle 2 period September – November (b)

3.3. Application for Minimizing Spray Drift

To find the ideal condition for spraying in ideal time and condition of each parameter based on reference and previous study is still hard to achieve. Therefore, software to determine nozzle sprayer size consider to weather condition will help overcome this limitation. The prototype interface of application to select the nozzle sprayer based on weather conditions while the knowledge is represented trough decision tree (Figure 7.a). Rainfall is the first parameter which decides do spray or do not spray, because spray application will not conducted in rainy day and herbicide particles will run off along with rain water. Wind becomes second parameter, following by temperature and humidity. Weather parameters can be inputted manually or can use weather data taken from the past data which stored in database.

For example, this application applied using weather data of Jonggol. Weed control performed on normal weather condition, this application will recommend the use of medium sized nozzle (Figure 7.b). While the condition in which the large wind speeds (15-20 km/h) the system will recommend the use fine nozzle size. Air assist technology use to avoid drift due to wind speed and turbulence of wind direction. When applied an extreme weather conditions, for example wind speed > 20 km/h, rainy, wind direction that is rapidly changing, the air humidity is very low and very high temperatures, the system recommend do not spray (Figure 7.c).High wind speed and wind direction change will make a big drift. It occur spray turbulence which resulted particles of spraying drop to non-target weed effectively. In [1], temperature and humidity closely related to particle evaporation. The very low of humidity and very high temperature will make spraying particles evaporate faster in the air before reaching the crop, and the particles that have reached the plant cannot work effectively because it will evaporate faster.



(a) (b) (c)

Figure 7. Sprayer droplet selection based on weather condition. Knowledge representation (a), application in normal weather condition (b) application in extreme weather condition (c)

4. Conclusions & Future Directions

The DSS for weed applications has been developed and tested with a real data set acquired from remote sensing devices. The proposed system can generate optimal spray scheduling and recommend the proper size of nozzles used for spray application on paddy crops based on the weather condition, and thus introducing minimal spray drift and bad environmental impact.

In our current implemented prototype data acquisition from remote sensing devices such as NOAA, TRMM and MODIS is carried out using separate application interfaces. The future enhancement is to build one application interface to acquire data set from these sensing devices, allowing the easy and faster acquisition of required data sets from more diverse sources of remote sensing devices in an integrated manner. Moreover, due to the variability of weather characters and planting time periods in different geographical areas, the use of fuzzy inference system for improving the time scheduling of weed spraying is highly recommended for the future system development.

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