Determination of Buffer-Zones using Agricultural Information System

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***Abstract* – The estimation of agricultural yield is a challenging and essential task for every farmer. In most countries worldwide, above 70% of the population practice and depend upon agriculture for their lives and livehoods. In attempts to increase agricultural productivity, farmers often apply pesticides excessively. This practice has led to problems with spray drift, along with many others, a process by which liquid sprays are transported and cause harm to adjacent crops and other non-target areas. Although investigation has also been directed toward pesticide drift caused by agents such as wind, boom height, and driving speed, this effort has thus been insufficient. Therefore, our research focuses on modelling to account for these factors to create buffer zones around crops to spray drift during pesticide application. We employed a GIS model to capture spray area points. Spray drift distances calculated with values representing the aforementioned agents are appended to these geographic points of the farm to establish a buffer zone area.**

***Keywords* – Buffer zone, GIS, pesticide application, spatial-temporal, spray drift.**

1. Introduction

As the world's population has increased rapidly, the necessity for food has increased as well. Most developing countries are predominantly agricultural, i.e. with approximately 70% of the population practicing agriculture. Agricultural expansion and development in the past forty years have increased the quantity of food produced and improved the quality of fresh food available worldwide [1]. Despite this ongoing expansion, inefficient agricultural practices persist in many parts of the world, because of a lack of modern tools and technologies [2], [3]. These inefficient practices hamper the efficiency of crop production.

One of the major current efforts in the agricultural sector is to mitigate excessive pesticide usage with the help of scientific guidance and timely information. A pesticide is any substance or mixture of substances intended to prevent, destroy, repel, or mitigate any pest [4]. They often contain active ingredients that make them toxic, therefore, their presence in the environment poses a threat to non-target living organisms [5]. Over 1 billion pounds of pesticides are used in the United States (US) annually, and approximately 5.6 billion pounds are used worldwide [6]. Excessive use of pesticides is harmful in multiple ways. For example, the use of pesticides can impose a financial burden on farmers, and excessive pesticide usage may lead to immunity in pests, which ultimately makes them more harmful to crops. Worldwide, it is estimated that approximately 1.8 billion people engage in agriculture, most use pesticides to protect their produce [4]. Farmers usually follow unscientific cultivation practices provided by local pesticide marketers. As a result, the farmers are often employing incorrect, untimely and excessive pesticides. The improper handling of pesticides violation of safety rules and application procedures [7] can lead to increased spray drift that can harm non-target organisms, including humans [8], and particularly children whose parents work and live in the vicinity of the agricultural fields [9]. Recently, the Agricultural Health Study has produced evidence of increased incidence of cancers of the prostate, lung, colon, pancreas, and bladder, leukemia, and multiple myeloma with increase lifetime exposure to certain pesticides [10]. Indiscriminate usage of pesticides is similarly harmful to other non-target organisms.

When pesticides are applied, a key issue is the risk of 'spray drift' beyond the field boundary. This usually occurs when winds are strong enough to break up and carry away spray droplets. This is an

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important and costly problem facing commercial and private users. In addition to the added cost to farmers, this problem results in environmental contamination. Accurate placement of pesticide droplets on to crop and weed surfaces is a key step in guaranteeing high quality food production. Applicators have a responsibility to all parties to hold human and environmental safety as their highest priority, even if that means a small loss in revenue.

A Geographic Information System (GIS) is a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data from different historical periods and at various scales of analysis [11]. By applying GIS technology, agricultural operations are able to manage resources and responsibilities more efficiently, develop data portals that disseminate vast amounts of agricultural data and interactive maps, and support farming communities. Agriculture operations are ultimately connected with natural resources that have spatial features. Spatial data is information about a physical object that can be represented by numerical values as a geographical coordinate system. In general, spatial data represents the location, size and shape of an object on planet Earth such as a building, lake, mountain or township along with attributes that provide more information about the entity that is being represented. Temporal data means that the data are defined to have some time-related information associated with them; time might be in the past, present or possibly future. This spatial-temporal data plays an important role in identifying the issues that are critical for crop growth management.

In this work, an attempt is made to show how spatial-temporal information system integrated with agriculture can be useful to visualize applicable buffer zone for pesticide usage. This study demonstrates that spatial-temporal records on crop field location can be used to create crop maps. Using a GIS, the zones of potential exposure to agricultural pesticides and proximity measures can be determined. Consequently, in this study, web based application is developed to establish and inform the importance of width of no spray zones around the agricultural fields. The outcomes of the model have many benefits into agricultural pesticide usage management and farming practices. To the best of our knowledge, there isn't any research project that brings together all of the growers, dealers, agriculture engineers, agrochemical companies, consumers, and suggest growers how to visualize pesticide usage considering spray drift buffer-zone. Our solution will help growers make decisions about crops and how best to use pesticide; similarly, dealers will obtain help about finding harvests; lastly, people will learn about the foods which they consume. Moreover, variation in the amount of pesticide use can be observed among farmers when they grow the same commodity within a county, and these variations of use can be associated with agronomic, socio-economic, and environmental and biological factors.

The rest of this paper is organized as follows. Section 2 discusses some related work. Section 3 introduces conceptual spatial-temporal agricultural data model. Sections 4 presents spray drift dynamics. Overviews of the system implementations are given in Section 5. Section 6 concludes the paper and points to directions for future research.

2. Related work

Substantial investments are being made in efforts to improve the efficiency of agricultural processes. Zhang et al. [12] developed a field-level geographic information system (FIS) that provides specific analytical functions useful for research in precision farming. They integrated spatial data from a variety of sources with different accuracies and resolutions. In addition, a discrete model was developed to simulate the time lag inherent to yield sensors on combine harvesters. Precision farming is a knowledge-based system that integrates many advanced information technologies, which enables farmers to apply precise amounts of fertilizers, pesticides, water, seeds or other inputs to specific areas where and when they are needed for optimal crop growth. An excellent reference by Zhang et al. [13] discusses natural-resource variability, impact of precision-agriculture technologies on farm profitability and environment, innovations in sensors, controls, and remote sensing, as well as applications and adoption trends of precision-agriculture technologies. Lu et al. review the current state of the art of precision farming and its major components, and discuss its economic feasibility and potential implications for agricultural structure and rural communities in [14]. Ruß and Brenning [15] present a spatial cross-validation data mining technique to predict yields in-season using available geo-coded data sets.

Spray drift has been studied extensively in a series of field trials by Ganzelmeier et al. in [16] and Rautmann et al. in [17]. The results of these studies are used in pesticide registration in the European Union (EU). Specifically, the 90th percentile of all measured 'drift values' is commonly applied in ecotoxicological risk assessments. The available data from these field trials form a large database, which is suitable for probabilistic estimation of spray drift based on Monte Carlo simulation [18]. The effectiveness of buffer zones has been demonstrated on controlled, experimental farm plots in [19], [20]. Designing variable-width buffers to match spatially variable input loads has also been discussed. Bren [21] developed a method that consists of dividing the length of a field into segments and evaluating the buffer needs of each segment separately with the goal of achieving a constant ratio of buffer area to runoff area into which it drains. Dosskey et al. extended this buffer-area-ratio approach to quantify the level of control and applied it to agricultural landscapes in [22]. Nevertheless, a need was identified for a more flexible, practical, and visual approach, which is now possible through the use of emerging spatial-temporal information and technologies, detailed digital landscape data, GIS software, and affordable computers capable of calculation-intensive analyses.

3. Overview of the spatial-temporal agricultural conceptual model

A spatial database management system (SDBMS) provides storage structures and basic operations for spatial data manipulation, whereas geographic information systems (GIS) provide the mechanisms for analysis and visualization of geographic data [23]. In this way, geographic databases (GeoDB) are collections of georeferenced spatial data, stored by SDBMS and manipulated by GIS [24]. GeoDB must be designed following a methodology that includes the conceptual, logical and physical design phases. It has been acknowledged for several decades that conceptual models allow describing the requirements of an application in terms that are as close as possible to users' perception.

A GeoDB stores three large data categories: conventional data without geographic reference (e.g., product), geographic phenomena perceived in object view (e.g., cities, farms), and geographic phenomena perceived in field view (e.g., temperature). The main UML-GeoFrame contribution consists of providing a constructed group that enables the designer to carry out the modeling of geographic phenomena perceived in field view appropriately [25]. Therefore, the UML-GeoFrame uses the same constructs of UML class diagram, such as classes and subclasses containing attributes and operations, and associations between classes, also enabling the specification of aggregation and composition [26].

Land parcels can have agricultural use or be buildings; however we only kept agricultural use for the sake of the simplicity. Farmlands owners' (ID and name are known), who may change in time, and their geometries in space are recorded in the database. For farm lands, soil type, vegetation, and elevation are recorded; the first two in terms of regions, while the last one in terms of points. The UML diagrams below correspond to the modeling of object classes related to the implementation of buffer zone calculator inside a geographic information system. These class diagrams explain the application area of interest and the theme classes, describing the several themes that will portray this area. Our case study focuses on a particular agricultural area in Izmir, Turkey.

The partial conceptual schema for spatial-temporal agricultural information system depicted in Figure 1., UML-GeoFrame diagram describes our GIS project in this research. In our work, we have basically chosen UML because this language became standard method to model information systems. This provides a precise constraint representation of complex geometries and has emerged to improve the efficiency of systems analysts and the quality of spatial database design.

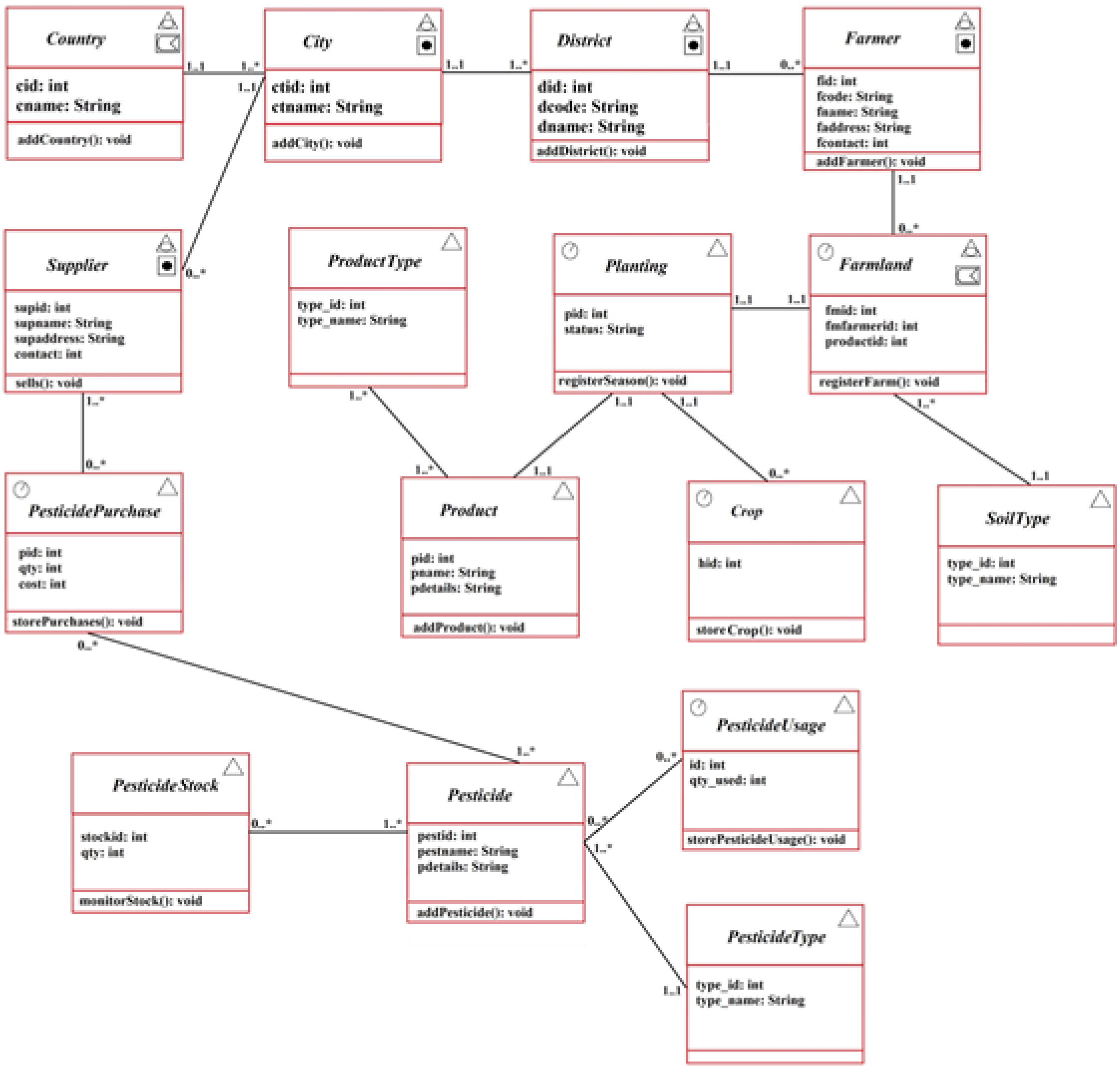

Figure 1. The partial conceptual schema of a spatial-temporal agricultural information system.

4. Spray Drift and Buffer Zone Preliminaries

Spray drift can be defined as unwanted physical movement of spray droplets into non-target areas by air movements while application and after application [27]. Vapour drift occurs by non-target movement of vaporized pesticide related to its volatility characteristics and evaporation. This kind of spray drift is much more depended to pesticide characteristics than the used spraying techniques [28]. Evaporation can happen during or after application [27]. Particle drift occurs when spray droplets move in air from nozzle to target surface when they have pulverizated. During this movement droplets are very open to environmental effects. Air movements and wind can cause to spray drift. This kind of spray drift takes place during application.

Spray drift is being affected by application features and environmental conditions. The spraying process can be divided into two zones; close to the nozzle where droplet movement is influenced by the sprayer and at distance from the sprayer where droplet movement is controlled by prevailing meteorological conditions. Important factors of spray drift are viscosity and evaporation characteristics, weather conditions, droplet size, travel speed, nozzle type, boom height, spray pressure, nozzle spacing and attention/talent of operator [28]. Wind speed is the most important meteorological factor on spray drift and it has a direct effect on drift. Increasing of wind speed will increase drift, proportionally. Drift will be uncontrollable at over 10-12 km/h wind speed and spraying must be finished over that wind speeds [27]. Moreover, nozzle pressures must be adjusted into values which are well-matched with wind speed. Wind direction is as important as wind speed and must be considered also. Consequently, wind direction must be monitored continuously and buffer zone must be carefully calculated.

Total spray drift, the size of the non-targeted area affected by spray drift and its severity depend on weather conditions and decisions made by the operator of the sprayer. As the liquid emerges through a nozzle at high discharge speed, it is quickly broken into droplets. The droplets have enough inertia to drag ambient air into motion, which may be one of the primary functions of the sprays, or may have an important effect on its performance. In the vertical sprays that spray high enough above the ground, the inertia of the droplets is determined by their weight (or buoyancy forces) rather than initial momentum, and eventually they can reach their terminal velocity [29]. Figure 2. displays basic spray drift dynamics.

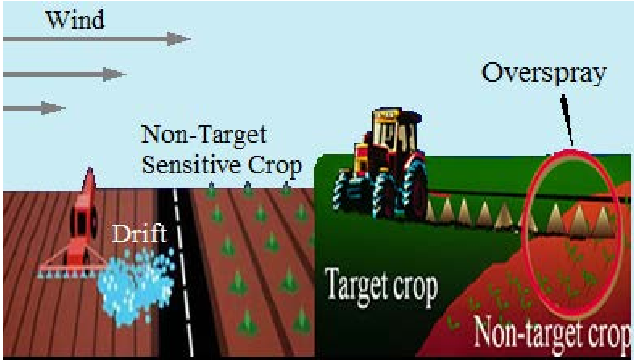

Figure 2. Spray drifts dynamics.

When applying pesticides, applicators must consider the pest being controlled, the correct pesticide dosage, human health risk related to the pesticide, and its impact on non-targeted organisms in the environment. In recent years, more attention has been paid to spray drift and its impacts on the environment. Most pesticide labels now contain information on the required distance between the site of spray application and environmentally sensitive areas (*i.e.*, buffer zone). A buffer zone, unless otherwise specified on a product label, is defined as the distance between the point of direct pesticide application and the nearest downwind boundary of a sensitive habitat [30].

Sarker and Parkin developed a model to predict spray drift [31] that the wind tunnel measurement is used to describe it along with other most important parameters as depicted in equation1.

$$D_p = 1.612\, x\, 10^{-3} (C_{dis})^{5.973} \left(\frac{h}{D}\right)^{-0.180} \left(\frac{h}{x}\right)^{1.0451} \theta^{-0.2664} \left(h\sqrt{\frac{u}{Q}}\right)^{1.618} \quad (1)$$

where

D_p = drift potential

C_{dis} = coefficient of discharge

D = equivalent diameter of the orifice (m)

h = nozzle height (m)

x = downwind distance (m)

q = the angle in the vertical plane that the spray nozzle makes to the airstream.

u = wind speed ($m\ s^{-1}$)

Q = discharge ($m^3\ s^{-1}$)

A spray droplet is released from the boom at a specific height above the sea level while the wind force or velocity is applied behind it. High velocity currents break spray droplets, which enables them to be driven from target area. This travel distance establishes a 'buffer zone' around the perimeter of each block where pesticide is applied.

5. Implementation

Here we describe the stages involved in the implementation of our farming information system and discuss the methods we have used to collect and evaluate the data.

Farmers can sign up on the website, and enter information about their farming procedures. In order to retrieve and display general GIS information, farmers must indicate their farmland's location. They will enter which harvests they cultivate on their land, how much they harvest and when they harvest. Moreover, farmers will enter information about pesticides used, how much is used and when. Dealers will sign up on the website and enter their information, such as business addresses and phone numbers. They will be able to search for harvests in the system. When they find a harvest that matches the criteria they specify, they can send an offer to the owner of the harvest using the farmer's contact information or the website's messaging system. Agricultural engineers will also use the system to offer farmers professional guidance. Engineers may sign up on the system after confirmation by the system administrator. An agricultural engineer may volunteer to help farmers or be hired as a consultant. Each agricultural engineer is assigned to certain territory by the system. When a farmer needs help, he can use the messaging system to contact assigned engineers. Agrochemical companies (suppliers) can use the system to provide the type of pesticides suggested by the agricultural engineers to the farmers, and to advertise their products. Farmers will obtain their pesticides by ordering online.

Table 1. The summary of generated both spatial and non-spatial data.

FARMID	LOCATION	SOILTYPE	DATE	OWNER
1	[27.200789093840285, 38.371217593655274], [27.200553059446975, 38.370914780270674], [27.20040285574214, 38.37054467330204], [27.200295567381545, 38.37030914970009], [27.200832009184523, 38.3700904485262], [27.20119678961055, 38.37015774126548], [27.201561570036574, 38.37086431125006], [27.201561570036574, 38.37086431125006]	Sandy	2015-04-30	Peter bimbo
2	[27.20112158730217, 38.37076056040232], [27.201163832094153, 38.37083573830923], [27.20117389037796, 38.37085939567639], [27.20127648487278, 38.37084099550262], [27.201303306962927, 38.37082995539611], [27.20128587260433, 38.370763189001785], [27.20125033334883, 38.370717451357514], [27.201205406333884, 38.37067486800757], [27.20112359895893, 38.37070325691031], [27.201092083003005, 38.37072638860063]	Clay	2015-04-30	Peter bimbo
3	[27.20415794836299, 38.368409231262554], [27.20340692983882, 38.367753108533016], [27.204501271116897, 38.3672988662357], [27.205466866362258, 38.36782040344571], [27.205853104460402, 38.36793816939234]	Clay	2015-04-30	Izzet Tanurgan
4	[27.198793530333205, 38.36918759813687], [27.198321461546584, 38.36858195311162], [27.198493122923537, 38.368127716016495], [27.199329972136184, 38.36780806598128], [27.200016617643996, 38.36932218523194], [27.19915831075923, 38.36967547516565]	Saline Soil	2015-04-30	Yasin Yakup
5	[27.205080628264113, 38.370124094903666], [27.205531239378615, 38.3699222164042], [27.203106522429152, 38.368391286121735], [27.202849030363723, 38.36849222757721]	Peaty	2015-04-30	Yasin Yakup

Table 1. displays a summary of both spatial and non-spatial data generated using our farming information system. This includes the farm ID, its physical location, soil type and owner information.

Figure 3. presents tools used to generate the synthetic data needed to achieve our stated objective for this project. Both spatial and non-spatial data can be generated using these tools. Spatial data represent the physical location of a crop field on the earth's surface. Non-spatial data explain the physical location of the farm and describe the crop field that has been created, as illustrated in Figure 4.

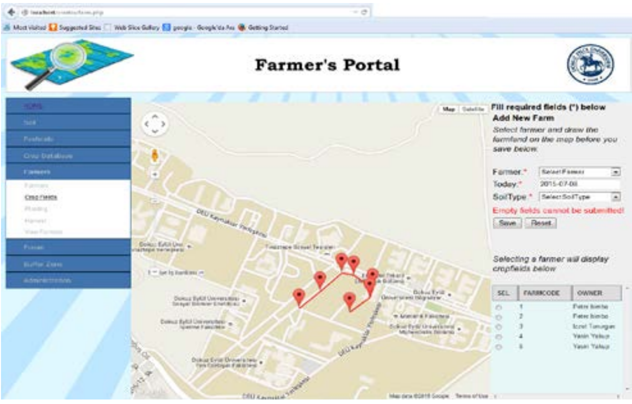

Figure 3. Tool used to collect both spatial and non-spatial data

Figure 4. A farm or crop field that has been created.

To determine the buffer zone, a simulation was used to predict the distance a spray drift could travel following pesticide application. Distance simulation requires data entries of the spraying method (broadcast, banded/boomless, directed), speed of the sprayer, target application rate, spacing of nozzles, driving speed, and boom height. The simulation uses a derivation of an equation for displacement (1) to calculate the distance in meters. Steps for completing a simulation are as follows:

Step 1- Select the farm that is to be sprayed (Figure 5.).

Step 2- Fill out the form to calculate the distance as shown in Figure 6. This includes spraying method (broadcast, banded/boomless, or directed), speed of sprayer, target application rate, spacing of nozzles, wind velocity (retrieved online from a meteorological website), driving speed, and boom height. The spraying nozzle flow rate is calculated using calibration calculator [32] and drift potential is calculated using equation 1.

Step 3- The drift distance in meters is displayed on the website. After the distance is obtained, it is appended on every point of the polygon representing the crop field to create a buffer zone able to absorb the chemicals and prevent spreading to non-target areas. Each polygon is coded with information that indicates the chemical used, as well as the rate at wind speed spreads. Figure 7. illustrates the buffer zone that should be observed during pesticides application based on our model, represented by the area in blue.

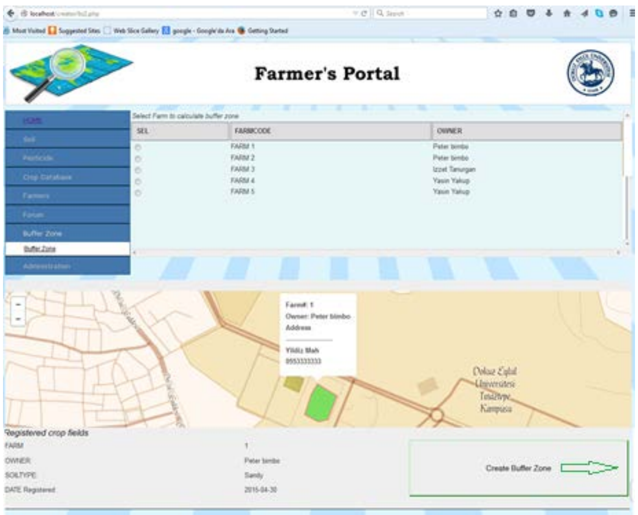

Figure 5. A farm or crop field is displayed on the map with the owner's information.

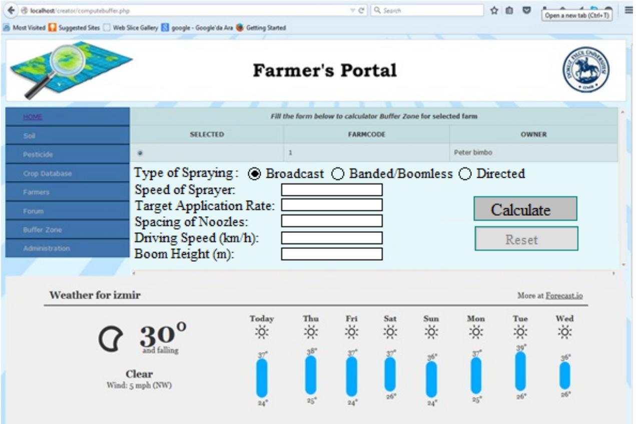

Figure 6. Calculation of the drift distance.

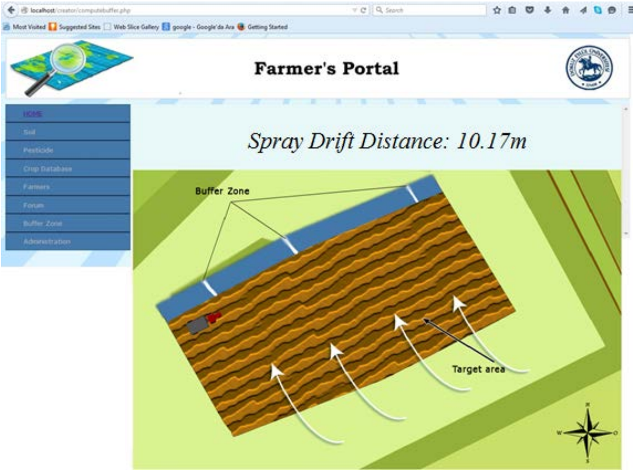

Figure 7. The buffer zone that should be observed when applying pesticides.

Drift distance calculations vary based on wind velocity and boom height, as shown in Table 2., which shows relative drift distances for water droplets based on initial wind speed (5, 6, 8, 10, 16, 19 km/h), driving speed (8, 7, 6, 5, 4, 3 km/h), and boom height (3 m). For example, spray application carried out at a wind speed of 3km/h, driving speed of 8km/h, and boom height of 3 m was able to travel 8.61m, as depicted in Figure 8.

Table 2. Synthetic data obtained using our methodology which includes data about wind speed, driving speed, and drift potential.

Wind speed(km/h)	Driving speed(km/h)	Drift Potential(m)
5	8	10.17
6	7	10.17
8	6	10.95
10	5	11.74
16	4	15.65
19	3	17.21

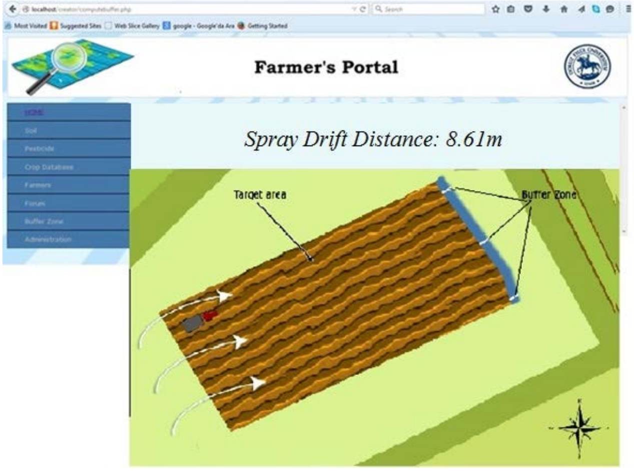

Figure 8. The buffer zone that should be observed when applying pesticides.

Based on our computer simulations of drift distances with the range of variables discussed above, we determined that changes in wind velocity, boom height, and driving speed had the most significant influence on the drift distances of water droplets. Lower wind speeds are associated with shorter distances traveled by water droplets beyond the target area, while higher wind speeds can move water droplets longer distances.

6. Conclusions

In this paper, we propose an agricultural information system that will enable farmers to visualize buffer zones for pesticide usage with modeling that accommodates both spatial and temporal attributes. Our study demonstrates that through GIS, successful implementation, scientific monitoring, layout, and timely information, farmers can be provided with tools to guide scientific decision making and increase productivity. This system enhances the quality and value of agricultural produce and saves resources. When spatial data are available at the farm or section level, GIS can be used to generate spatially explicit maps showing the locations of non-target crop fields potentially at risks from spray drift. Proposed agricultural information system helps to overcome market problems and decrease ecological and environmental harm caused by pesticides. In addition, it can be utilized to estimate potential cropland areas at risk of unintended pesticide exposure from nearby spray drift.

Better understanding of new technologies at spraying will help to reduce drift. Sufficient knowledge about spray drift, factors of spray drift and application tools will make a better control on drift management. Variation in pesticide use can be compared against agronomic, socio-economic, environmental, and biological factors. Ultimately, this system will enable conservation of resources and minimize environmental pollution caused by overuse of chemicals**.** The techniques developed in this project may be linked to decisions support systems to maximize the effectiveness of plant protection products and minimize risks to public health and the environment from agricultural spraying activities.

This research also provides a strong foundation for future work. One area of future focus will be to apply data mining techniques to the acquired geographic data. Future research into the efficacy of buffer zones on operational farms will provide data regarding additional variables that influence buffer trapping efficiency (e.g., moisture condition, rainfall intensity and duration, and buffer vegetation) to enhance the predictive power of our models. Extending buffer zone models to application of pesticides to orchards by broad air-assisted sprayers will also be a target of future research. We anticipate extending this project to a large number of stakeholders namely farmers, dealers, agricultural engineers, agrochemical companies and consumers. In the next phase of our project, we plan to make our system accessible through the smartphones that most farmers now own and use. This will enable farmers to use modern farming techniques that will considerably increase productivity.

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