Department of Environment and Geography

University of York

Assessment Submission Cover Sheet 2018/19

This cover sheet should be the first page of your assessment

Exam Number: Y3864317	**Module Code:** ENV00091M
Module Title: Pollution monitoring, assessment and control	**Assessment Deadline:** 6th March 2019

I confirm that I have

- **conformed with University regulations on academic integrity**
- **please insert word count** 2816
- **not written my name anywhere in the assessment**
- **checked that I am submitting the correct and final version of my coursework**
- **saved my assessment in the correct format**
- **formatted my assessment in line with departmental guidelines**
  - I have ensured my work is compatible with black and white printing
  - I have ensured the compatibility of any graphs or charts included in my submission
  - I have used 12pt font (preferably Arial or similar)
  - I have ensured all pages are clearly numbered using the system 1 of 6, 2 of 6 etc. Page 1 will be your Assessment Submission Cover Sheet
  - I have ensured my examination number is on every page of the assessment

PLEASE TICK BOX TO CONFIRM

V

Please note: if you have any questions please refer to the FAQs available on the VLE (Student Admin Hub).

Proposal of strategies available to reduce Herbicide concentrations in water bodies

1. INTRODUCTION

It is important that crop yields are at a maximum to feed our growing population, however crops are often subject to weed infestations. Problems like this occur on a global scale, so farmers have resorted to chemical weed controls such as herbicides. The addition of herbicides to crops allows for the prevention of weeds, but also contributes to maximum crop yields as there is the ability for closer crop spacing which leads to a higher crop plant population (Imoloame, 2017).

As herbicides are a chemical and can pose as a threat to the environment, there are a variety of regulations and laws relating to the use of herbicides that should be considered. The laws and regulations aim to ensure that best practice is being met were possible during herbicide application, handling and disposal. The following regulations (**Table 1**) show the laws and regulations that should be obliged with to show that those using herbicides follow good practice on using, storing, transporting and disposing of herbicide chemicals.

Table 1. Legislation that should be complied with when handling herbicides. (Legislation gathered from DEFRA, 2006).

Legislation
Food and Environment Protection act
Control of Pesticide Regulations 1986
Plant Protection Products Regulations 2005 & Plant Protection Products (Basic Conditions) Regulations 1997
Wildlife & Countryside Act 1981
Groundwater Regulations 1998
Environmental Protection Act 1990
Environment Act 1995
Waste Framework Directive 75/442/EEC
Waste Management Regulations 2006

Sometimes there are accidents that cause for regulations to be broken, which is the case for a recent herbicide product that has been launched and used by farmers. It has come to the attention of the local Environment Agency and the local water company that the herbicide is being detected in surface waters in the catchment area as well as in drinking water supplies. The detection of herbicide in water has caused for serious concern due to the possible impacts on the catchments ecology and

population health. The recommended concentration of herbicide in drinking water is 0.1 microgram per litre which was set by the European Drinking Water Directive (DWI, 2010), however if concentrations exceed this it is likely to pose as a threat to human health. Human health effects can include acute effects such as nausea, irritation to the upper respiratory tracts, seizures and abdominal pain. Although pesticides detected may be at trace levels, high concentration levels can cause chronic effects such as lung, kidney and liver problems as well as the possibility of cancer (Trautmann *et al*., 2012, Tsai, 2013). The possible ecological effects vary but the most serious ecological effects that herbicides can cause include loss in production, changes to development, growth and behavior, alteration of diversity and the loss of important species (Zacharia, 2011).

The extent of the effects that the pesticide has on ecology and human health is dependent on the chemicals that present in the herbicide as well as the concentration levels, however measures should be taken to avoid these effects. Therefore, this report is going to consider all possible approaches that can be applied to reduce concentrations of the herbicide in local water bodies.

2. POTENTIAL PATHWAYS OF CONTAMINATION

Before considering strategies that are available to reduce herbicide concentration in water bodies, it is important to consider the potential pathways of entry for herbicides into water bodies. By assessing the potential pathways for entry, the correct management strategies can be applied to reduce herbicide concentration levels in water bodies.

There are various potential pathways for herbicides to enter water bodies which can either be diffuse (indirect) or point (direct) sources. Diffuse pathways are those that pass through the soil before entering the water body such as surface run off or leaching, whilst point sources are those that come from a localised event and enter the water body at a specific location (Carter, 2000). A number of different diffuse and point sources that could be a potential pathway for the herbicide found in local waters are collated in **Table 2**.

Table 2. Potential pathways for herbicide to enter waterbodies. Some pathways are point sources which are direct, whilst others are diffuse meaning they are indirect sources.

Source	Description
Diffuse sources	
Spray Drift	When spraying of herbicides is made in close proximity to surface water. Spray drift can be influenced by weather and bankside vegetation (Gilbert & Bell, 1988).
Leaching	Transport of soluble to surface water through ground water (Carter, 2000).
Surface Runoff	When the infiltration capacity of a surface is exceeded, residues move along the surface rather than been absorbed (Carter, 2000)
Drainflow/ throughflow	Land drainage that removes water from soils that are slowly permeable and the lateral movement of water below the surface where land drainage is not present (Carter, 2000).
Volatilization/ Precipitation	Herbicides that are applied and enter the atmosphere before been re-precipitated (Bloomfield *et al*., 2006)
Point sources	
Farm yard activities	Inadequate handling and storage often causing spillages. Also comes from cleaning contaminated farm machinery near boreholes (Carter, 2000)
Overspray/direct contamination	Spillages, contaminated vehicles, overspray during herbicide application (Carter, 2000).

3. POTENTIAL STRATEGIES

In order for herbicide concentrations to be reduced in the catchment, a variety of strategies have been set forward. The strategies mentioned in this report are those which are most suited to the problem of reducing herbicide concentrations, and are likely to have the most effect if implemented.

3.1 HERBICIDE APPLICATION STRATEGIES

A method which may be considered by farmers to prevent herbicides from entering into water bodies, is to consider using cultural practices that reduce the need for high concentrations of herbicide application and therefore optimize the application of herbicides. Cultural practices that may be considered are likely to reduce the emergence and growth of weeds but also increase crop yields (Norsworthy & Frederick, 2005). Such methods can be achieved by narrow the row spacing

between crops (Norsworthy & Frederick, 2005), adjusting the dates of seed planting and introducing crop rotations (Schrieber, 1992). In addition to changing their farming methods so that less herbicide is needed, farmers should consider the uncontrollable factors such as wind and rainfall so that optimal herbicide application is achieved.

Wind speed and direction should be considered during herbicide application, particularly in areas where surface water is in close proximity. It is recommended that wind is under 10mph, therefore, farmers should consider applying herbicides when wind is below 10mph, with the herbicide been applied at a constant wind speed and when wind is blowing away from water sources (Davis *et al.,* 2015). It has been recommended that early mornings and nights are best for applying herbicides (Celen & Onler, 2011).

Precipitation trends should also be considered when applying herbicides as rainfall is likely to impact transport pathways of herbicides (Bloomfield et al., 2006), particularly as rainfall has found to increase the amount of herbicide that leaves the soil in runoff during rainfall events (Bloomfield *et al.,* 2006). Run off during rainfall can also promote erosion of soil and the transportation or sorbed herbicides, which can often be a dominant pathway for herbicides entering surface waters (Petersen *et al.,* 2002). Assessment of weather conditions is key to ensuring that herbicides are applied at the correct time to avoid increased run off and spray drift.

3.2 FARM MANAGEMENT STRATEGIES

One possible approach to improving the problem of herbicide in surface waters would be the addition of vegetation zones such as hedgerows, buffer strips and fields margins, which act as a buffer between the surface which is receiving herbicide application and water sources (Haddaway *et al*., 2018, Muscutt *et al*., 1993). These vegetation zones can also be beneficial for habitat improvement and flow capture (Stutter *et al*., 2012).

The addition of vegetation zones in farming practices allows for the flow of water to be reduced as it passes across the vegetation zone due to factors such as the type and density of vegetation. A reduction in flow is beneficial as it ensures that suspended sediment is deposited, thus decreasing the transportation of herbicide contaminants (Haddaway *et al*., 2018). The reduction in flow also allows for water

run off to be infiltrated into the strip, therefore decreasing the volume of water and the dissolved herbicide within it (Bharati *et al*., 2002).

As well as decreasing the flow of water, vegetation strips can act as a driver for increasing soil structure (Kavdir & Smucker, 2005) and soil stability (Schultz *et al*., 1995). The addition of vegetation zones will also allow for roots to create macropores, which are a beneficial method for enhancing rain infiltration (Ghestem *et al*., 2011), therefore playing the role in reducing water run off (Yu *et al.*, 2016) and herbicides reaching surface waters.

In addition to vegetation zones, biobeds could also be implemented as this method aims to reduce the risk of herbicide contamination in surface water when filling, cleaning and storing farm machinery (Castillo *et al*., 2008). Biobeds consist of a pit in the ground, followed by a layer of straw, peat and soil, with the addition of a grass layer on top (Castillo *et al*., 2008). Lined biobeds which have a synthetic permeable layer to separate the pit from the ground and a collection for drainage water (**Figure 1**) are already implemented in the UK and have already been high successful and are an inexpensive method to mitigate the leaching of herbicides into surface waters (Kreuger & Nilsson, 2001).

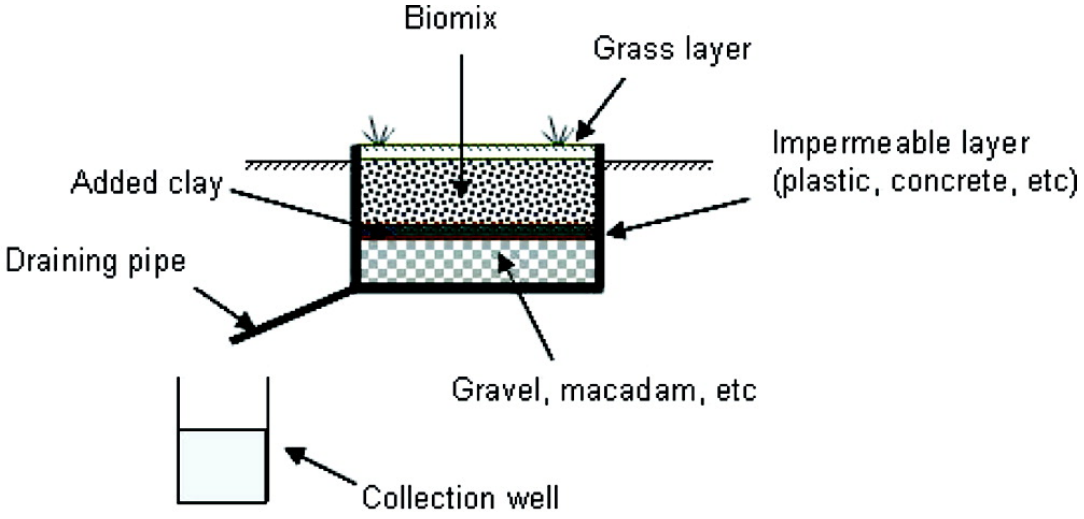

Figure 1. Aspects of a Lined biobed systems that can be implemented to catch water run off during loading and cleaning of spraying vehicles. Source: Castillo et al., 2008.

3.3 TECHNOLOGICAL APPROACHES

Spray drift is a significant pathway for herbicides to enter surface water, so therefore approaches are needed to tackle this problem. One strategy that should be considered is the use of shields that cover the spray booms as these have been found to impact positively on the drift of herbicides during spraying (Felsot *et al*., 2010). The nozzles that are fixed to the spray booms should also be considered as a method to reduce spray drift, as the size of the droplet and nozzle can influence spray drift (Davis *et al.,* 2015). The larger the droplet the less chance of spray drift occurring as they fall at faster rates, therefore farmers should consider nozzle heads that are designed to reduce drift and increase droplet size (Celen & Onler, 2011; Davis *et al.,* 2015).

As herbicides often make their way into water bodies through spray drift and overspray, another possible approach to implemented is precision application of herbicides (Carvalho, 2017). The aim of precision application is to produce the highest yields possible with minimum input and minimal environmental pollution (Mondal & Basu, 2009), by applying integrated crop management through the use of information technologies and basic farming standards to analyse and manage changes of farms (Hosseini *et al*., 2010). This method allows for farmers to gather information of crops and to assess the inputs and rates of herbicides needed (Salehi *et al.,* 2008). By implementing this strategy, farmers would be able to reduce the potential of surface water contamination from herbicides (Krishnan *et al.,* 2006) as it will reduce the over application of herbicides (Sudduth *et al*., 2001).

3.4 AGRICULTURAL STEWARDSHIP SCHEMES

There are several agricultural stewardship schemes that should be considered when looking at appropriate mitigation methods for herbicides in surface water. This includes Countryside Stewardship which is funding for farmers so that they can make environmental improvements (Gov UK, 2019). Within the Countryside stewardship scheme is a project called Catchment sensitive farming which looks at ways to reduce water pollution caused by farming (Gov UK, 2019). The Catchment sensitive farming project provides farmers with education and advice, so that farmers located in catchment sensitive areas know how to manage their land effectively without causing further environmental harm (Gov UK, 2018).

As many farmers are unaware of the potential threats that herbicide application has on the environment, it may be beneficial to use an approach that looks at increasing farmer awareness and educating them about the problem. There is currently a scheme called the Voluntary initiative that aims to promote the responsible use of herbicides and pesticides from farmers to ensure that the environment and water is protected. The initiative also aims to improve farmer's knowledge on pesticides as well as providing them information on the correct practices such as application timing, frequency and storage of herbicides (The Voluntary Initative, n.d., a).
In addition to the water protection advice sheets that are available, the check it out tool which has been created, allows farmers to add details about their farm and their current practices so that they can be reviewed to see if they are meeting best practices. It also allows for a map to be built to assess in which areas of the country the best practices are taking place (The Voluntary Initative, n.d., b). There is a wide range of best practices including correct soil management, the creation of buffer zones and the filling, cleaning and application process of herbicides (**Figure 2**), with information readily available to farmers on the Voluntary Initiative website.

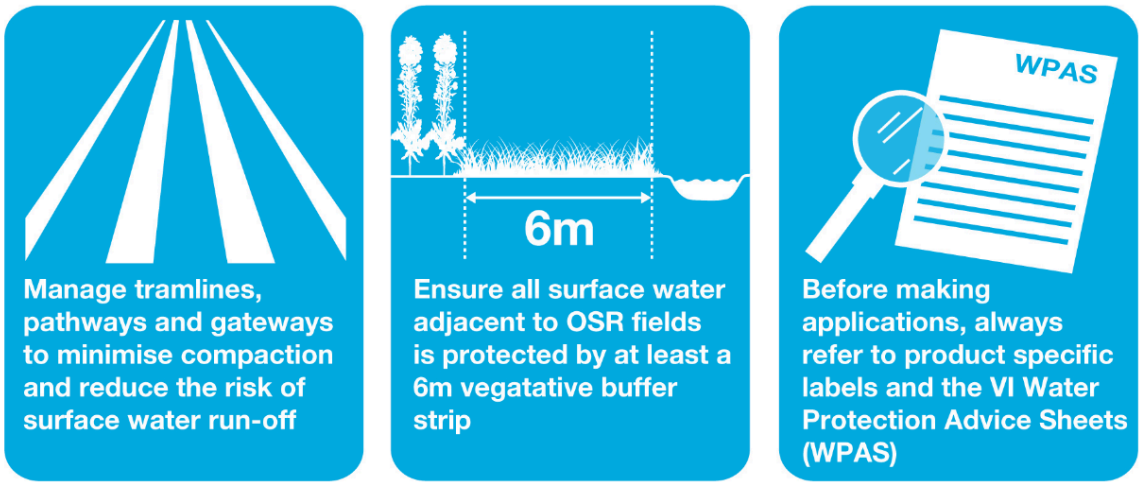

Figure 2. Best management practices which farmers can apply to their farming methods to ensure that all possible measures are been made to reduce herbicide pollution. (Source: The Voluntary Initative, n.d., c.)

By implementing agricultural stewardship schemes to farmers in the catchment area, they will be more aware of the consequences that their farming methods have on the environment. These approaches would can then allow for farmers to take the

necessary steps and precautions in farm management to decrease the chances of water pollution.

3.5 HERBICIDE PRODUCTION

As it was a newly developed herbicide that was detected in the water, the company responsible for producing the herbicide should also take into consideration approaches that could prevent the herbicide from having environmental consequences. A suitable approach to improving the herbicide could include green chemistry which aims to move away from traditional chemical herbicides by either reducing or eliminating any potential hazardous substances that are present in herbicides (O'Brien *et al.,* 2009). By applying green chemistry to the production of herbicides, there would be less chance of serious harm to the environment and human health. If a green chemistry product was readily available to farmers, then farmers may be more willing to move away from toxic chemicals and move more towards sustainable agriculture (O'Brien *et al.,* 2009). In the long run this approach has the potential to provide environmental safety, as there will be a decline of toxic chemicals, it does present some issues. There is the high possibility that farmers will need to purchase several different herbicides to target a variety of different weed, as the green chemistry approach results in company's focusing on a certain set of weeds in particular. This approach could be time consuming and costly to both farmers and production company (O'Brien *et al.,* 2009).

3.6 WATER TREATMENT APPROACHES

As the herbicide production company has consent to discharge liquid waste directly in to the sewage works, waste management strategies should be considered to reduce herbicide concentrations present in waste water.

Waste water usually contains solids, metals, organics and oils which need to be removed (Ebrahiem *et al.,* 2017), so the treatment process has to be suitable to remove all waste. Even though there are currently waste water treatment measures in place they are quite basic and could be improved to ensure that herbicides are not entering back into water streams. One method which is appropriate for industrial waste water is Fenton oxidation process, which Is the reaction and removal or

organic matter by decomposing hydrogen peroxide in iron ions at acidic conditions to create oxidant hydroxyl 1(Kitis *et al.,* 1999). Following the decomposition of hydrogen peroxide, radical chain oxidations will take place which have been initiated by the hydroxyl radicals. This process is created so that a reaction between the radicals and organic matter will occur (Neyens & Baeyens, 2003). Using the Fenton oxidation process has proven to be reliable in removing agri-chemicals from waste water, as well as being a treatment that is less expensive than others as it can take place at room conditions (Aljuboury *et al.,* 2014).

As well as waste water, drinking water also had concentrations of herbicides present, therefore suggesting that the current treatment in place is not working efficiently enough to remove herbicides. The recommended concentration levels of herbicide in drinking water is 0.1 microgram per litre (DWI, 2010), therefore treatment should be occurring which ensures that drinking water is meeting this requirement. In addition to the current treatment in place an extra step may want to be introduced, which would involve using granular activated carbon which has been used in other treatment works due to its ability to reduce chemicals in water by adsorption (Lemley *et al.,* 1995). Granular activated carbon is highly porous due to been produced by treating carbon to steam at high temperatures. When the carbon is subject to high temperatures it can oxidise in CO_2 and steam, to cause gases to evacuate and the generation of pores in the carbons structure (Sharma & Bhattacharya, 2017). This process increases the surface area of carbon, which results in high absorption abilities. The granular activated carbon process then works in the form of pulling the contaminant from the water and bringing it to the surface (Sharma & Bhattacharya, 2017). Although it can be an appropriate method to remove herbicides from drinking water, granular activated carbon does need to have frequent filter changes, which can be costly in terms of timing (Sharma & Bhattacharya, 2017).

4. INFORMATION REQUIRED

Although there are several suitable approaches that can be used to tackle the herbicide problem, there are several important facts that are unknown. Therefore, before a final management strategy is developed there is a vast amount of information that should be collected and consider. This information collected is

important to ensuring that the correct management strategies are being put in place so that optimal results can be produced. The main information required for a management strategy to be developed is the chemical composition of the herbicide, the location and proximity of water ways and the current application practices of the herbicide, although there are a variety of other forms of information needed to support this. The following information collated in **Table 3** should be collected and understood before a management strategy is developed.

Table 3. Important information that is required so that the development of a management strategy can be created.

Information required	Rationale
Crop Type	Management strategies may vary depending on crop type. Crop type may also influence the amount of weeds present, which could effect the amount of herbicide needed.
Herbicide chemical composition	Different herbicide chemicals have different environmental effects with some been more toxic than others.
Timing, frequency and concentration of herbicide and sludge applied	If herbicide or sludge is applied during rainy season, applied often and applied at high concentrations then the threat differs.
Storage of herbicide on farms	If storage of herbicides is not correct then spills may occur which can enter water sources through runoff.
Machinery- what type and frequency of cleaning	If machinery is not cleaned regularly then contamination may occur. However regular cleaning may cause water runoff which is potentially damaging to the environment.
Location of factory and farmers using the herbicide	Location is unknown. Restrictions may apply for different areas such as if it is located in a catchment sensitive area.
Weather pattern/ climate of the area	More rain causes more run off, whilst high winds cause spray drift. It is therefore important to know the climate.
Proximity of water sources and water source characteristics i.e flow rate	Some water bodies may be more effected than others due to their proximity to herbicide application areas.
Known concentration of herbicide in water	Herbicide concentration may vary in water bodies at certain times of the year
Any known health effects?	Its hard to assess the effects that the herbicide will have from been in water bodies if health effects are not known.
Local ecology i.e protected species/areas	Herbicide application and potential strategies may be effected by protected species
Local legislation	May impact on what strategies can be implemented

5. CONCLUSION

Based on this report there are several strategies that could be implemented quickly as they are straightforward including applying herbicides at correct timings to avoid wind and rain and the Voluntary Imitative to educate farmers. Another strategy which could be implanted without been too costly includes vegetation zones, however this may take some time before it is in full use.

At this stage although some strategies could be implemented, an appropriate management strategy cannot be narrowed down, as there are still too many unknowns regarding the herbicide itself and the location of the problem. It is therefore suggested that the correct information is gathered before making a decision as to which strategy is best at reducing herbicides in local water bodies. The information required, once gathered may find that a variety of strategies should be implemented for the best possible management to be developed.

Word Count: 2816

REFERENCES

Aljuboury, D., Palaniandy, P., Aziz, H. A. & Feroz, S. (2014). A Review on the Fenton Process for Wastewater Treatment. *Journal of Innovative Engineering*, **2(3).**

Bharati, L., Lee, K-H., Isenhart, T. & Schultz, R. (2002) Soil–water infiltration under crops, pasture, and established riparian buffer in Midwestern USA. *Agroforestry Systems*, **56(3),** pp.249–57.

Bloomfield, J.P., Williams, R.J., Gooddy, D.C., Cape, J.N. & Guha, P. (2006). Impacts of climate change on the fate and behaviour of pesticides in surface and groundwater—a UK perspective. *Science of The Total Environment*, **369**, pp.163-177. Doi: https://doi.org/10.1016/j.scitotenv.2006.05.019.

Carter, A. (2000). How pesticides get into water- and proposed reduction measures. *Pesticide Outlook*, **11,** pp.149-156. Doi: https://doi.org/10.1039/b006243j

Carvalho, F. P. (2017). Pesticides, environment, and food safety. *Food and Energy Security*, **6(2),** pp. 48-60. Doi: https://doi.org/10.1002/fes3.108

Castillo, M.P., Torstensson, L. & Stenström, J. (2008). Biobeds for Environmental Protection from Pesticide Use—A Review. *Journal of Agricultural and Food Chemistry*, **56 (15),** pp.6206-6219. Doi: https://doi.org/10.1021/jf800844x

Celen, I.H. & Onler, E. (2011). Reducing Spray Drift, Pesticides in the Modern World - Pesticides Use and Management, Dr. Margarita Stoytcheva (Ed.), ISBN: 978-953-307-459-7, InTech. [Available from: http://www.intechopen.com/books/pesticides-in-the-modern-world-pesticides-use-and-management/reducingspray-drift accessed on 04/03/2019]

Davis, J.A., Barber, L.T., Scott, R.C. & Norsworthy, J.K. (2015). Mitigating pesticide spray drift.
University of Arkansas, United States Department of Agriculture, and County Govern ments Cooperating. [Available at: https://www.uaex.edu/publications/pdf/FSA2179.pdf accessed on 03/03/2019].

DEFRA (2006) Code of practice for using plant protection products. [Available from: http://www.hse.gov.uk/pesticides/resources/C/Code_of_Practice_for_using_Plant_Protection_Products_-_Complete20Code.pdf accessed on 01/03/2019]

Drinking Water Inspectorate (2010). Pesticides. [Available from: http://dwi.defra.gov.uk/consumers/advice-leaflets/pesticides.pdf accessed on 01/03/2019]

Ebrahiem, E., Al-Maghrabi, M.N. & Mobarki, A.R. (2017). Removal of organic pollutants from industrial wastewater by applying photo-Fenton oxidation technology. *Arabian Journal of Chemistry*, **10(2),** pp. 1674-1679. Doi: https://doi.org/10.1016/j.arabjc.2013.06.012

Felsot, A.S., Unsworth, J.B., Linders, J.B.H.J., Roberts, G., Rautman, D., Harris, C. & Carazo, E. (2010) Agrochemical spray drift; assessment and mitigation—A review, *Journal of Environmental Science and Health,* **46**, pp.1-23. Doi: https://doi.org/10.1080/03601234.2010.515161

Ghestem, M., Sidle, R.C. & Stokes, A. (2011) The influence of plant root systems on subsurface flow: implications for slope stability. *Bioscience*, **61**, pp. 869-879. Doi: https://doi.org/10.1525/bio.2011.61.11.6

Gilbert, A.J. & Bell, G.J. (1988). Evaluation of drift hazards arising from pesticide spray application. *Aspects of Applied Biology*, **17**, pp.363–375.

Gov UK (2018). Catchment Sensitive Farming. [Available from: https://www.gov.uk/guidance/catchment-sensitive-farming-reduce-agricultural-water-pollution accessed on 04/03/2019]

Gov UK (2019). Countryside Stewardship. [Available from: https://www.gov.uk/government/collections/countryside-stewardship-get-paid-for-environmental-land-management#catchment-sensitive-farming accessed on 04/03/2019]

Haddaway, N.R., Brown, C., Eales, J., Eggers, S., Josefsson, J., Kronvang, B., Randall, N.P. & Uusi-Kämppä, J. (2018). The multifunctional roles of vegetated strips around and within agricultural fields. *Environmental Evidence*, **7(14).** Doi: https://doi.org/10.1186/s13750-018-0126-2

Hosseini, M., Chizari, M. & Bordbar, M. (2010). Evaluation of the possibility of precision agriculture from the view point of Agricultural experts in Fars Province. *Iranian Agricultural Extension and Education Association*, **6(2),** pp.35–47 http://waterquality.cce.cornell.edu/publications/CCEWQ-03-ActivatedCarbonWtrTrt.pdf accessed on 04/03/2019]

Imoloame, E.O. (2017). Evaluation of herbicide mixtures and manual weed control method in maize (*Zea mays* L.) production in the Southern Guinea agro-ecology of Nigeria. *Cogent Food & Agriculture*, **3**, pp. 1-7. Doi: https://doi.org/10.1080/23311932.2017.1375378

Kavdir, Y. & Smucker, A.J. (2005) Soil aggregate sequestration of cover crop root and shoot-derived nitrogen. *Plant Soil*, **272,** pp. 263-276. Doi: https://doi.org/10.1007/s11104-004-5294-x

Kitis, M., Adams, C. & Daigger, G. (1999). The effects of Fenton's reagent pre-treatment on the biodegradability of non-ionic surfactants. *Water Research*, **33**, pp.2561–2568. Doi: https://doi.org/10.1016/S0043-1354(98)00476-X

Kreuger, J. & Nilsson, E. (2001), Catchment scale risk mitigation experiences-Key issues for reducing pesticide transport to surface waters. Presented at BCPC Symposium Proceedings NO. 78: Pesticide Behaviour in Soil and Water, pp.319-324. [Available from: https://www.slu.se/globalassets/ew/org/centrb/ckb/publikationer/bcpc_symposium_78.pdfn accessed on 04/03/2019]

Krishnan, M., Foster, C.A., Strosser, R.P., Glancey, J.L. & Sun, J. (2006) Adaptive modelling and control of a manure spreader for precision agriculture. *Computers and Electronics in Agriculture,* **52**, pp.1-10. Doi: https://doi.org/10.1016/j.compag.2005.11.005

Lemley, A., Wagenet, L. & Kneen, B. (1995) Activated carbon treatment of drinking water. Cornell Cooperative Extension, College of Human Ecology. [Available from: http://waterquality.cce.cornell.edu/publications/CCEWQ-03-ActivatedCarbonWtrTrt.pdf accesses on 04/03/2019]

Mondal, P. & Basu, M. (2009) Adoption of PA technologies in India and Some Developing Countries: scope, present status and strategies. *Progress in Natural Science,* **19(6)**, pp.659-666. Doi: https://doi.org/10.1016/j.pnsc.2008.07.020

Muscutt, A.D., Harris, G.L., Bailey, S.W. & Davies, D.B. (1993). Buffer zones to improve water quality: a review of their potential use in UK agriculture. *Agriculture, Ecosystems & Environment*, **45**, pp.59-77. Doi: https://doi.org/10.1016/0167-8809(93)90059-X

Neyens, E. & Baeyens, J. (2003), A review of classic Fenton's peroxidation as an advanced oxidation technique. *Journal of Hazardous Materials*, **98**, pp.33–50. Doi: https://doi.org/10.1016/S0304-3894(02)00282-0

Norsworthy, J. K. and J. R. Frederick. 2005. Integrated weed management strategies for maize (Zea mays) production on the southeastern coastal plains of

North America. *Crop Protection*, **24**, pp.119–126. Doi: https://doi.org/10.1016/j.cropro.2004.06.014

O'brien, K.P., Franjevic, S. & Jones, J. (2009). Green chemistry and sustainable agriculture: The role of biopesticides. *Advancing Green Chemistry.* [Available from: http://advancinggreenchemistry.org/wp-content/uploads/Green-Chem-and-Sus.-Ag.-the-Role-of-Biopesticides.pdf accessed on 04/03/2019]

Petersen, C.T., Holm, J., Koch, C.B., Jensen, H.E. & Hansen, S. (2002). Movement of pendimethalin, ioxynil and soil particles to field drainage tiles**.** *Pest Management Science,* **59,** pp. 85-96. Doi: https://doi.org/10.1002/ps.609

Salehi, S., Rezaei-Moghaddam, K. & Ajili, A. (2008) Application of yield monitoring technologies: a model for sustainable agriculture. *Iranian Agricultural Extension and Education Association*, **4**, pp. 15–32

Schreiber, M. M. (1992). Influence of tillage, crop rotation, and weed management on giant foxtail (Setaria faberi) population dynamics and corn yield. *Weed Science*, **40**, pp.645–653. Doi: https://doi.org/10.1017/S0043174500058252

Schultz, R.C., Collettil, J., Isenhart, T., Simpkins, W., Mize, C. & Thompson, M. (1995) Design and placement of a multi-species riparian buffer strip system. *Agroforestry Systems*, **29(3),** pp.201–26. Doi: https://doi.org/10.1007/BF00704869

Sharma, S. & Bhattacharya, A. (2017) Drinking water contamination and teatment techniques. *Applied Water Science*, **7**, pp.1043-1067. Doi: https://doi.org/10.1007/s13201-016-0455-7

Stutter, M.I., Chardon, W.J. & Kronvang, B. (2012) Riparian buffer strips as a multi- functional management tool in agricultural landscapes: introduction. *Journal of Environmental Quality*, **41(2),** pp.297–303. Doi: https://doi.org/10.2134/jeq2011.0439

Sudduth, K.A., Drummond, S.T. & Kitchen, N.R. (2001) Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. *Computers & Electronics in Agriculture*, **31**, pp.239–64.

The Voluntary Initiative (n.d., a) About us. [Available from: https://voluntaryinitiative.org.uk/about/about-us/ accessed on 05/03/2019]

The Voluntary Initiative (n.d., b) Check it out tool. [Available from: https://checkitout.voluntaryinitiative.org.uk/tool/ accessed on 05/03/2019]

The Voluntary Initiative (n.d., c) OSR Herbicides? Think Water. [Available from: https://voluntaryinitiative.org.uk/schemes/stewardship/osr-herbicides-think-water/ accessed on 05/03/2019]

Trautmann, N., Porter, K.S. & Wagenet, R.J. (2012) Pesticides: Health effects in drinking water. Pesticide Management Education Program: Cornell University. [Available from: http://psep.cce.cornell.edu/facts-slides-self/facts/pes-heef-grw85.aspx accessed on 01/03/2019]

Tsai, W-T. (2013) A review on environmental exposure and health risks of herbicide paraquat. *Toxicological & Environmental Chemistry*, **95(2),** pp.197-206. DOI: https://doi.org/10.1080/02772248.2012.761999

Yu, Y., Loiskandl, W., Kaul, H.P., Himmelbauer, M., Wei, W., Chen, L. & Bodner, G. (2016) Estimation of runoff mitigation by morphologically different cover crop root systems. *Journal of Hydrology*, **538**, pp.667-676. Doi: https://doi.org/10.1016/j.jhydrol.2016.04.060

Zacharia, J.T. (2011). Ecological Effects of Pesticides, Pesticides in the Modern World - Risks and Benefits, Dr. Margarita Stoytcheva (Ed.), ISBN: 978-953-307-458-0, InTech, [Available from: http://www.intechopen.com/books/pesticides-in-the-modern-world-risks-and-benefits/ecological-effects-of-pesticides accessed on 01/03/2019]