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CONTROLLING TECHNOLOGIES ADOPTED FOR THE MINIMIZATION OF NON-POINT SOURCE POLLUTION FROM THE AGRICULTURE RUNOFF

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ABSTRACT

Nitrogen and phosphorus runoff from the croplands are the primary sources for the inputs of nutrients to the water causing eutrophication. Industrial releases from point sources can be managed by stringent rules and regulations. However non-point sources of pollution canot be stopped and there is a need for minimizing the pollution linked with it. Many researchers proposed several methods to treat the agricultural runoff like controlling at source, controlling at the process, and end of the treatment. In this current review, significant technologies used to manage agricultural runoff are summarized.

KEY WORDS : Eutrophication, Non-point source, Agricultural runoff, Nutrients, and global.

INTRODUCTION

Environmental pollution is one of the most significant challenges in conserving safe water resources (Evans *et al.,* 2019). Over the last few decades, numerous technologies were emerged to treat the effluents from the industries and domestic sewage (Crini and Lichtfouse, 2019). While point sources can be managed, non-point sources cannot be and hence, these are to be constantly monitored, to have a check on the deterioration of the environment. One such non-point source of pollution which is of great concern is runoff from agriculture, which is the surface outflow from the farmlands, and the primary sources for the excess water are rainfall and irrigation (Wang *et al.,* 2018). Generally, the runoff water consists of complex pollutants such as phosphates, ammonia, nitrates, persistent organic pollutants, etc. Nitrogen and phosphorus are essential for aquatic plants' growth as they are critical in limiting nutrients during eutrophication.

Eutrophication levels are significantly affected by pollution due to the non-point source arising from agricultural practices (Zhang *et al.,* 2019; Xia *et al.,* 2019). Eutrophication caused by human-made activities is becoming a significant issue as it is identified to have higher potentialities in affecting humans' health and the aquatic ecosystems. Figure 1 depicts the "cyanobacterial mats" in the Indian Yamuna river, resulting in the shortage to access clean drinking water leading to the water crisis (Pericherla *et al.,* 2020). Simultaneously, continuous inputs of POPs and heavy metals from the runoff results in bioaccumulation and biomagnification, causing health risks. Thus, it is essential to reduce pollution to control the aquatic bodies' eutrophication, guard the water bodies, and maintain drinking water qualities.

The three major controlling strategies for minimizing the pollution caused by the agricultural runoff are controlling at source, controlling at the process, and ending treatment. Pollution controlling at the source reduces the application of nitrogen and phosphorus in addition to leaching, particularly tillage conservation, managing fertilization, and water-saving irrigation (Chilundo *et al.,* 2018; Xia *et al.,* 2019). Pollution controlling during the process is intended to eliminate contaminants by the space-time continuum of runoff from the agricultural fields to the ecological ditches (Wu *et al.,* 2013).

End treatment is the final option for treating contaminated water to avoid water damage only if the contaminants below the safe levels (Díaz *et al.,*

Fig. 1. Cyanobacterial mats formation in Yamuna river

2012). Even though each approach has its principles, they control non-point source pollution runoff to different degrees. Nevertheless, it is challenging to integrate the wide variety of treatment options. Agriculture helps develop the national economy and increases an individual's GDP in countries like India, Indonesia, and China (Cordell *et al.,* 2009). The growing pressure of food enhanced synthetic fertilizers, which are threat for agriculture during the past decades.

Nitrogen and phosphorus diffusivities in the soils are completely different. Cookson *et al.,* (2000) reported that dihydrogen phosphates diffusion coefficients are one-millionth of nitrates which affect the runoff of nitrogen and phosphorus. Seasonal variabilities enhanced the difficulty in regulating the loss of nutrients from runoff. Nitrogen and phosphorous are considered primary sources of agricultural pollution, leading to the accumulation in the receiving water. Carpenter *et al.,* (1998) reported that excessive accumulation of these nutrients causes water deterioration, an increase in algal blooms, and biodiversity loss. Owing to inadequate controlling strategies, non-point agricultural pollution is becoming a worldwide concern. The current review provides an overview on significant technologies used to manage agricultural runoff in India.

Advancements of research in source control technologies

Agricultural runoff water consisting of pesticides in dissolved forms, sediments, and nutrients causes adverse problems, including translocation of recalcitrant chemicals, loss of nutrients, and soil erosion (Blankenberg *et al.,* 2015). Generally, tillage practices improve the surface's roughness and reduce the runoff, which results in the decrease of pollution loads and emission runoff at the source. Rice is a staple food in India and nearly 1/3rd of the population relies on this food by planting more than one hundred and sixty-four million hectares worldwide. Rice is considered a semi-aquatic plant and requires more water for its irrigation, leading to massive runoff (Mahajan *et al.,* 2017). The nitrogen and phosphorous in the dissolved forms and other organic sediments create pollution in the surrounding water (Arnhold *et al.,* 2014).

Reduced tillage and no-tillage methods

Even though tillage methods distribute the soil surface evenly, conservation methods play a significant role in protecting soil surface and prevent erosion (Plaza-Bonilla *et al.,* 2013). Additionally, tillage practices improve the soil's structure and enhance the organic content, further enhancing the "infiltration to surface runoff ratio" by reducing evaporation (Schmidt *et al.,* 2019). Clausen et al. (1996) carried out studies on croplands of Vermont, USA, and reported that tillage methods reduced the runoff by sixty-four percentage. Liang *et al.* (2016) said that non-tillage practices reduced the runoff by 26 % in rice-planting watersheds. Conservation tillage techniques minimize the intensities and impact the precipitation by protecting the soil surfaces.

Over recent years, biochar is applied to the soil to enhance porosity and protect the soil (Meier *et al.,* 2017; Xia *et al.,* 2019). Won *et al.,* 2016 reported that applying rice straw, gypsum, and polyacrylamide to the cabbage field reduced the total nitrogen by 34% and suspended solids by 86%: Lee *et al.* (2015) conducted studies on applications of biochar on the soil to prevent the erosion and reported that amending polyacrylamide and biochar reduced loss of soil by 70% during the precipitation of 33 mm/day. Biochar and its application to the soil for nutrient fixation studies are worthy and further required to carry out in the future (Sun *et al.,* 2020).

Rotation tillage

This method reduces the agricultural runoff consisting of dissolved nitrogen (Liu *et al.,* 2014). Nevertheless, these practices enhanced the soils' compactions during long-term operations, leading to the build-up of phosphorous on the soil's surface and increases phosphorous runoff. Tiessen *et al.,* 2010 stated that practicing conservation tillage techniques in Canada's prairies reduced the total nitrogen to forty-one percent, whereas total phosphorous runoff increased by forty-two percent. Rotation tillage techniques are one amongst other methods that are mainly used for controlling nutrient loss and runoff. Liu *et al.*, (2014) change the conservation tillage to rotation tillage and revealed that rotation tillage techniques are the better alternative to minimize the phosphorous runoff. Changing of tillage techniques reduced the total dissolved phosphorous and total phosphorous runoff by forty-six percent and thirty-eight percent; this might be attributed to the compaction of alleviating soils, decreasing phosphorous accumulation in the soil surface. During the long-term operation, residues of crops in conservation tillage enhanced the agricultural runoff. Thus, rotation tillage reduces the duration of exposure between the crop and runoff residues, which lowers the phosphorous from the crop's detritus. Daverede *et al.*, 2003 related the runoff phosphorous afterward non-tillage and chisel plough farming and revealed that the non-tillage method reduced the dissolved phosphorous by sixty percent. Thus, the tillage practice selection must be built on the soil, climatic and crop conditions.

Management of fertilizers

Management of fertilizers is an alternative method for source control which is practiced widely. In agricultural sectors, nitrogen and phosphorus-containing fertilizers are commonly used. However, the competence of nitrogen fertilizers is different from crop to crop. Cassman *et al.* (2012) testified that the efficacy of nitrogen fertilizers for crops like rice, wheat, and maize are thirty-one percent, eighteen percent, and thirty-seven percent, respectively (Figure 2). Tan *et al.* (2013) conducted studies on a wheat-maize crop rotation system to know the nitrogen loss and effects on fertilizers' application. They revealed that nitrogen runoffs are minimized by the controlled release/application of fertilizers. However, phosphorous's controlled release to the paddy soil reduced to sixty-two percent, and corn is thirty-three percent. Optimization and application rate are considered essential to control the loss of nutrients (Hua *et al.*, 2017) as the losses are seasonally varied. During the precipitation, ammonia loss is decreased, and nitrate loss is increased gradually.

Irrigation by water-saving techniques

Heavy rainfall and improper field drainage system enhance the surface runoff. In the paddy cultivation season, the surface runoff is very high as this cultivation is coupled with the monsoon, and nitrogen losses are found to be eighty-six percent; this might be attributed to the "Conventional Flooding irrigation techniques (CFIT)" which maintains the flood water level in the paddy fields. Thus, integrating tillage, management of fertilizers techniques with AWDT will enhance the crop yield. However, these techniques cannot prevent the runoff flow to the nearby water receiving bodies, but

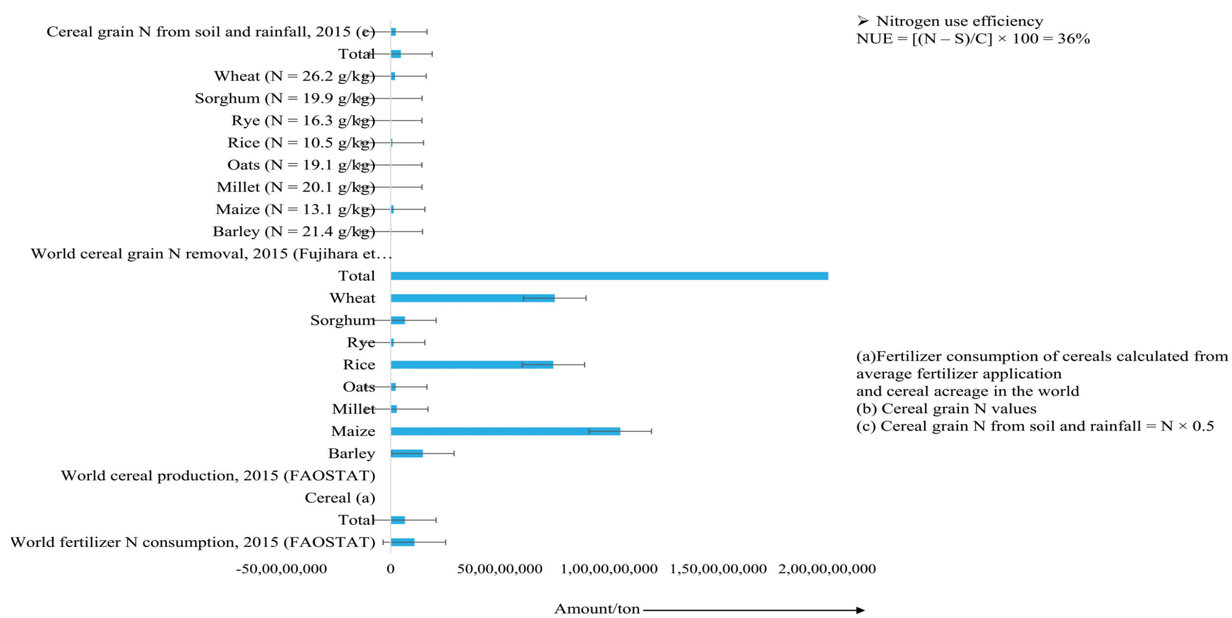

Fig. 2. Illustrates the NUE calculations and worldwide data of nitrogen fertilizer usage (Keeney, 1982).

these techniques minimize the nitrogen and phosphorous losses during runoff. Nevertheless, it is still challenging to attain safe discharge concentrations.

Advancements of research in process control technologies

Control technologies intend to eliminate the pollutants during runoff. The ditches are engineered structures distributed widely around the adjacent farmlands. Ecological ditches reduce the nutrient runoff like "surface-flow-constructed wetlands" before these substances are discharged into the nearby waters (Moeder *et al.,* 2017); thus, the land requisition, maintenance, and investments on the land might be minimized. Hence, this technology is considered promising to prevent the runoff at the control in heavily populated areas.

Ecological Ditches

Ditches are engineered structures developed to remove the runoff nutrients from agriculture by sedimentation, sorption, uptake by plants, transformations, and microbial activities (Zhao *et al.,* 2017; Xia *et al.,* 2019). Agricultural ditches are an essential part of the drainage and irrigation systems extensively distributed amongst the farmland. The traditional ditches (agricultural and ecological) form a "sediment-aquatic plant-microorganism system" that helps introduce aquatic plants, substrates, and interception amenities (Kumwimba *et al.,* 2018). Periphyton is considered a crucial component in the ecological ditches. Ecological ditches are broadly distributed and might help to remove the contaminants by the complexation and adsorption mechanisms. Periphytons are the larger biomasses and sensitive to water quality and remove nitrogen and phosphorus. Figure 3 depicts ditches with vegetation and nutrients exclusion efficiencies.

Microbial treatment

The removal efficiencies of nitrogen and phosphorous by ecological ditches could not be related to standard sewage treatment techniques owing to disadvantages and low efficiencies of phytoremediation intended for agricultural

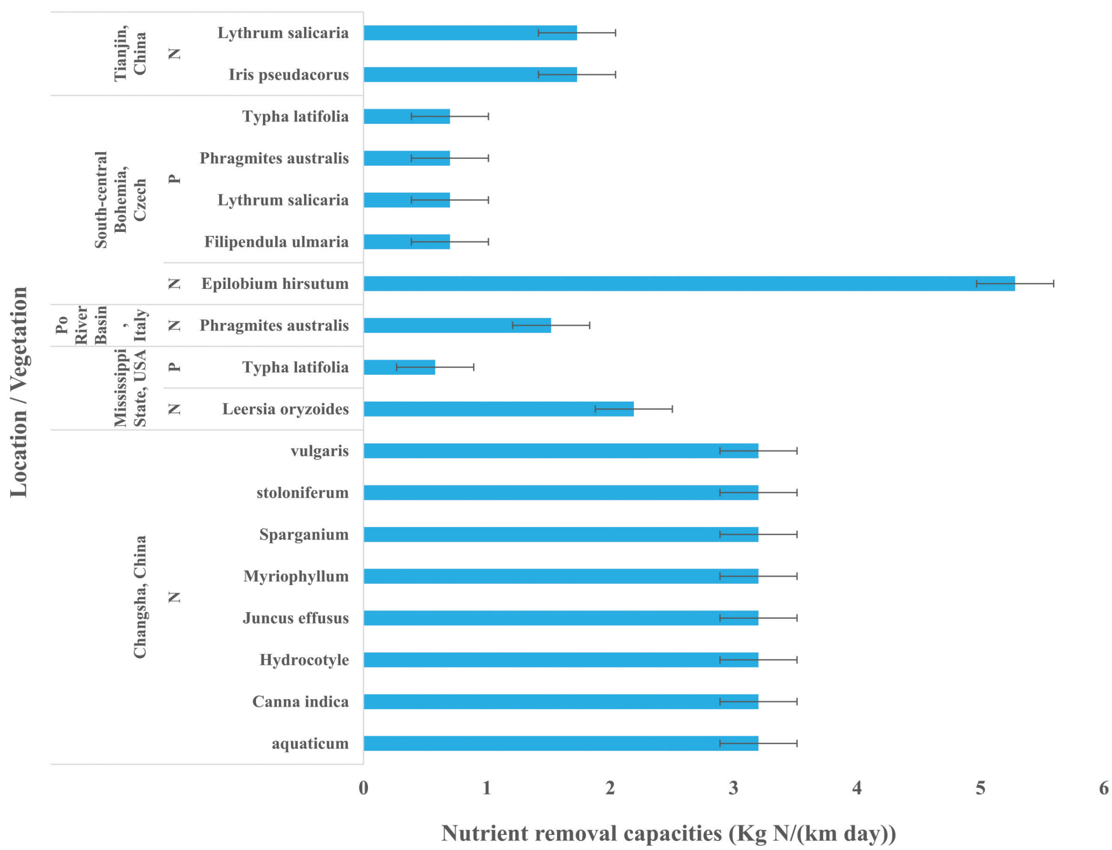

Fig. 3. Illustrates the nutrient removal efficiencies by the vegetated plants in the ecological ditches (Vymazal and Bøezinová, 2018; Flora and Kröger, 2014; Li *et al.,* 2016).

irrigation and during heavy precipitation. These technologies are cost-effective, simple, and eco-friendly for treating domestic sewage treatment, animal wastewater, and wastewater from dyeing industries. Thus, microbial treatment techniques are the better options for the next-generation ecological ditches. Kassab *et al.* (2010) removed organic loads by treating wastewater with activated sludge processes are used, and it involves an anaerobic/anoxic/aerobic process (A2/O).

Advancements of research in end treatment technologies

To prevent the nutrients runoff to the nearby receiving water bodies, end treatment of the runoff water is the last barrier. The standard end treatment technologies include constructed wetlands (CWL), Buffer strips (BS), and Infiltration systems (IS). CWL is the unified system for the "soil-plant microorganism"; these are considered transitional zones and present between receiving waters and farmlands. CWL has good adsorption/absorption and settlement capacities for organic matter and nutrients. Further, it was found that contaminants in CWLs removals are highly dependent on the seasons. Valkama *et al.* (2017) conducted nutrient removal efficiency experiments seasonally and found that total phosphorous removal was high in June (twenty-eight percent) compared to February (five percent). In contrast, the nitrogen removal efficiencies were highest in July (eighty-two percent) and lowest in November (nearly four percent). CWLs might depend on the phytoremediation techniques as ecological ditches for the pollutant's removal.

Comprehensive controlling technologies for the agricultural runoff

As shown in Figure 4, several technologies have been proposed to control runoff, divided into three main categories. Conservation tillage, management of fertilizers irrigation by water-saving, ecological ditches, CWLs, and buffer strips are successfully studied and applied to control the agricultural

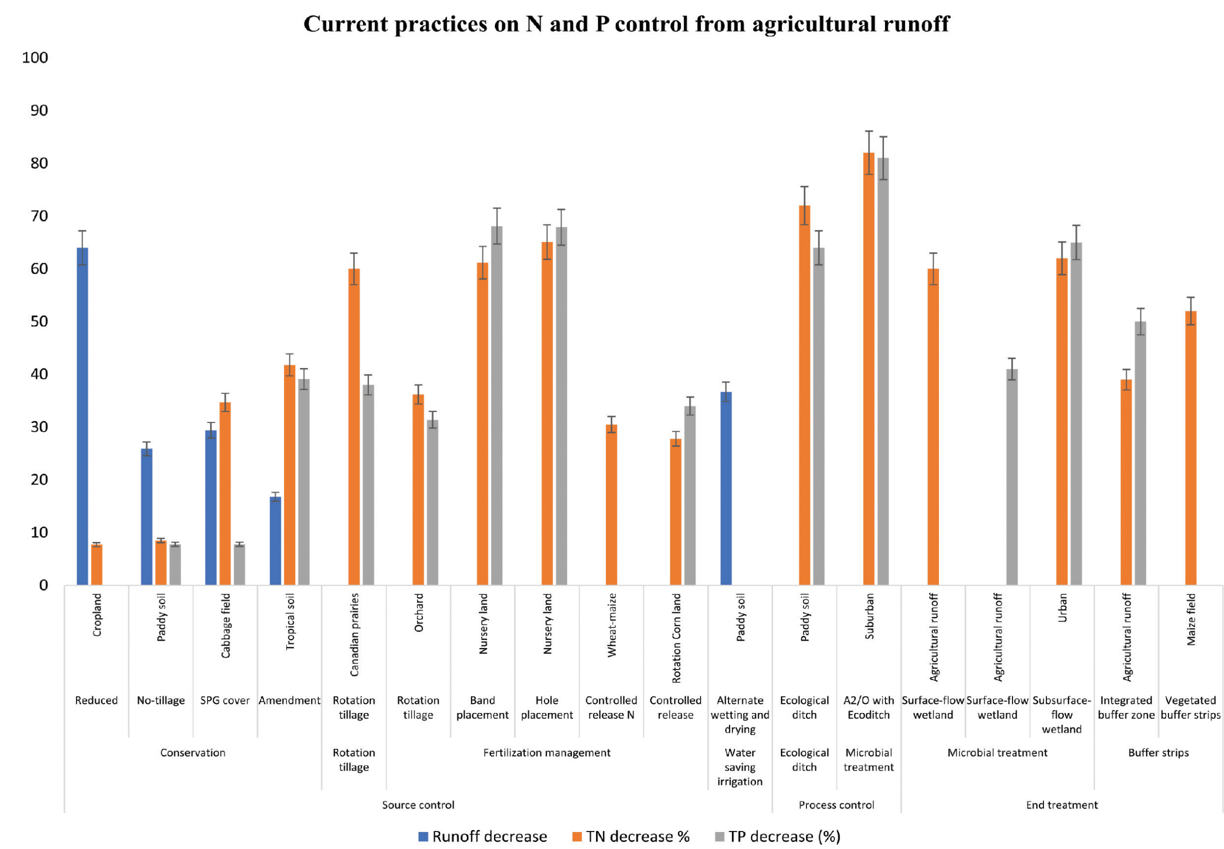

Fig. 4. Illustrates the agricultural runoff current controlling practices (Clausen *et al.*, 1996; Liang *et al.*, 2016; Won *et al.*, 2016; Lee *et al.*, 2015; Liu *et al.*, 2014; Liao *et al.*, 2017; Ye *et al.*, 2016; Zeng *et al.*, 2008; Tan *et al.*, 2013; Hua *et al.*, 2017; Kumwimba *et al.*, 2016; Sgroi *et al.*, 2018; Zak *et al.*, 2018; Salazar *et al.*, 2015).

runoff among the three. As stated before, the nutrients (nitrogen and phosphorus) must be removed from the runoff water before they are discharging into the nearby water bodies; however, no single technology meets such requirements. Thus, to minimize or control the runoff, the application of comprehensive techniques is required. To comprehensively understand the agricultural runoff treatment status, we carried out a scenario analysis based on the data presented in Figure 4. Paddy soils are considered to runoff source as paddy irrigation requires a large amount of water.

Controlling fertilizers, ecological ditches, non-tillage, and Surface-flow CWLs are very efficient in removing the nutrients from the paddy soil agricultural runoff. Nevertheless, these techniques have not achieved the targets of nitrogen and phosphorous removal. Since these techniques belong to controlling at the source, controlling at the process and end treatment technologies, they were presumed to be functional successively in the conjectural agrarian system. The controlled fertilizer technique is the most promising technique to reduce the nutrients in the runoff.

CONCLUSION

Even though many researchers proposed different types of practical techniques to control the runoff with different perspectives. Yet, these technologies not competent to do the job of runoff control. The present review identified the temporal location of the technologies and treatment competencies. It helped in utilizing farmlands system spaces and tried to minimize the agricultural runoff by integrating different efficient technologies with the existing technologies. The ideal characteristics to control the agricultural runoff are adaptability to the geographical location, and farmer awareness about the technology, Simple operational procedure without complexity, Low operational costs and treatment capacities with total degradations are required for organic matter and nutrients removal. To date, none of the current methods satisfied all conditions mentioned above. According to the literature available, integrating two or more technologies is effective in treating agricultural runoff.

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