SCIENCEFORECAST
A digital science library

Research Article
Published: 30 Apr, 2018

SF Journal of Environmental and Earth Science

Surface Runoff and Dissolved Phosphorus Losses in Response to Cropping System Changes in Acoastal Bay Watershed of Eastern China

Yanqiang Li[1,2], Weijn Yan[1], Fang Wang[1*], Shucong Lv[1], Qingqian Li[1] and Qibiao Yu[1]

[1]Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

[2]University of Chinese Academy of Sciences, Beijing, 100049, China

OPEN ACCESS

***Correspondence:**
Weijin Yan & Fang Wang, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.
E-mail: yanwj@igsnrr.ac.cn & wangf@igsnrr.ac.cn*

***Received Date:** 20 Mar 2018*
***Accepted Date:** 26 Apr 2018*
***Published Date:** 30 Apr 2018*

***Citation:** Li Y, Yan W, Wang F, Lv S, Li Q, Yu Q. Surface Runoff and Dissolved Phosphorus Losses in Response to Cropping System Changes in Acoastal Bay Watershed of Eastern China. SF J Environ Earth Sci. 2018; 1(1): 1014.*

ISSN 2643-8070

***Copyright** © 2018 Weijin Yan. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.*

Abstract

Agricultural fields have become major sources of phosphorus to aquatic environments. But less studies reported the phosphorus losses by surface runoff in response to the changes of cropping systems at different spatial scales. Here, we selected a typical coastal watershed to study P losses from agricultural fields with a variety of cropping systems. The results showed that rainfall intensity was the dominated factors for producing surface runoff. The surface runoff from modern cropping systems was significant higher than that from traditional cropping systems. DIP was the dominated loss form in traditional cropping systems, while the DOP had higher proportion in DTP from modern cropping systems. At agricultural field scale, modern cropping systems had higher DTP losses (average: 6.31 kg Phm^{-2}) than that of traditional cropping systems (average: 2.014 kg P hm^{-2}). The spatial patterns of DTP losses were impacted by the composition of cropping systems types at sub-watershed scale. TDP yields had positive relationship with the cultivated area of modern cropping system and negative relationship with traditional cropping system in sub watersheds. Annual losses were 18.61×10^5 kg P of dissolved P across the whole Dagu River watershed. Traditional cropping systems contributed 23.46% and modern cropping system contributed 76.54 % of DTP, respectively. Our study demonstrated that the change from traditional cropping systems to modern cropping systems can significantly enhance the DTP losses form agricultural system.

Keywords: Phosphorus; Cropping system; Surface runoff; Jiaozhou Bay watershed

Introduction

Phosphorus (P), as one of the basic nutrient element for agricultural production, has been used for improving food production across the world in recent decades years [1,2]. Large amounts of P fertilizers have been applying to the agricultural lands to maintain a high sustainability of food and energy productions [6-8], which resulted to the elevated level of P in soils due to low use efficiency of P fertilizers. Agricultural lands have become the major source of P for the receiving water bodies due to its accumulation in soils [9,10].

The main pathway of P losses from agricultural soils was via surface runoff [11,12]. Many studies reported factors influencing P losses via surface runoff, including rainfall, land covers, slopes, and so on. Agricultural cropping system, as a key driven force, can determine P budgets at three different scales, including agricultural fields, sub-watersheds and the watershed. However, less study reported how phosphorus losses by surface runoff respond to the changes of cropping systems at the three scales. China is the largest producer and consumer of fertilizers in the world. Particularly, Chinese traditional agricultural cropping systems have been significantly changed to modern cropping systems in order to obtain higher economic gains in recent decades. Correspondingly, one characteristic of agricultural production with modern cropping systems are to use large amounts of animal manure to promote the productions. On the other hand, water eutrophication is one of main environmental issues in China. Many surface waters, including lakes, rivers, estuaries and coastal seas, are suffering from agricultural nonpoint nutrient pollution. Here, we select a typical coastal watershed, the Jiaozhou Bay watershed, to study P losses from agricultural fields with a variety of cropping systems. The purposes of the study were to (1) analyze the chemical forms and amounts of P during the surface runoff losses in variety of cropping systems; (2) compare the differences of dissolved P lossing characteristics between traditional cropping systems and modern cropping

Table 1: Agricultural land and cropping system in sub watersheds.

Sub watersheds	Area (hm^2)	Ratio in total watershed %	Agricultural land (%)	Traditional cropping system (%)	Modern cropping system (%)
UpS	81540	13.77	72.23	62.00	38.00
ZHR	38741	6.54	72.58	50.00	50.00
CGR	22648	3.82	91.14	50.00	50.00
XGR	110523	18.66	71.49	41.00	59.00
WGR	72184	12.19	88.25	49.00	51.00
CZR	13632	2.30	85.02	48.00	52.00
LYR	35062	5.92	81.84	45.00	55.00
LHR	38040	6.42	85.90	40.00	60.00
NJLR	131407	22.19	77.73	49.00	51.00
TYR	24085	4.07	68.83	60.00	40.00
YXR	24354	4.11	46.41	44.00	56.00
Total	604400	100	73.05	48.80	51.20

Table 2: The soil characters of Dagu River watershed.

Crops	Depth cm	Bulk density g cm^{-3}	Sand %	Silt %	Clay %	pH	C g C kg^{-1}	Ng N kg^{-1}	Pg P kg^{-1}
Maize	0-30	46	45.31	32.25	22.44	5.33-6.64	8.41-11.03	0.98-1.40	0.09-0.19
Peanut						5.42	7.62	0.68	0.1
Verdant						5.23	5.41	0.68	0.23
Carrot						5.97-6.00	5.13-10.07	0.54-1.39	0.27-0.47
Cabbage						5.50-5.58	6.03-7.09	0.63-0.80	0.32-0.40
Ginger						6.02-6.11	10.62-10.49	1.23-1.92	0.30-0.49

Table 3: Characteristics of experimental plots.

Crop species		Length (m)	Width (m)	Area (m^2)	Slope (%)	Coverage (%)		
						June	July	August
Tradition	Maize	10	1.6	16	2	20	60	80
	Peanut	10	0.8	8	2	30	100	100
Modern	Ginger	10	0.8	8	2	10	20	20
	Verdant	10	0.8	8	2	10	30	50
	Cabbage	10	0.8	8	2	5	30	70
	Carrot	10	0.8	8	2	100	0	10

systems. Specifically, we hypothesize that the modern agricultural system with vegetable productions can export more P flux to coastal water bodies than any other agricultural productions along coastal areas of China.

Materials and Methods

Study area

The field observations were performed during the rainfall season from June 2017 to September 2017 in the biggest sub-watershed of Jiaozhou Bay – Dagu River watershed (E:119°46′ 58′-120°37′ 40′, N: 35°54′ 10′-37 °23′ 42′). Dagu River watershed, located in Shandong Province, Eastern China, covers a total area of 6044.8km^2, with agricultural lands being more than 70% of the watershed area. The watershed consists of eleven sub watersheds (Figure 1 and Table 1). Like most of the coastal areas in Eastern China, the agricultural productions experienced a thorough change in agricultural cropping systems in recent decades in the watershed. The traditional cropping systems include winter wheat - summer maize and spring peanut - summer maize production, while the modern cropping systems cover a variety of cropping systems, including double vegetables and spring/winter vegetable - summer corns productions. The agricultural land use ratios are 48.9% for traditional cropping systems and 51.1 % for modern cropping systems (Table 1). Fertilizers are increasingly applied in the watershed, and the application rates were ~140kg Phm^{-2} for traditional cropping systems and ~362.83kg Phm^{-2}for modern cropping systems. Normally, fertilizers are surface applied. The watershed was the temperate continental monsoon climate and the mean annual temperature equals 12.2°C. The 30 years annual rainfall volume is ranged from 500 to 700 mm, with 70-80% of total rainfalls occurred during June to September each year. The physical-chemical characteristics of the soils with different crops covered in Dagu River watershed were listed in Table 2.

Field sampling and experiment design

We selected six types of crop species fields as the experimental plots randomly, including two traditional crops (peanut and maize), and four modern crops (verdant, ginger, carrot and cabbage). Plot size for maize was 10m in length and 1.6m in width, and the sizes for other crop were 10m in length and 0.8m in width according to the farmers management, with a 2% slope (Table 3). The plots were isolated and

Table 4: Rainfall events and surface runoff in response to agricultural fields with different crops coverage.

Time	Precipitations mm	Precipitations intensitymm $^{h-}$1	Tradition		Modern			
			Peanut	Mazie	Ginger	Verdant	Cabbage	Carrot
23.06.217	8.00	6.00	-	-	-	-	-	-
24.06.2017	14.00	7.00	-	-	-	-	-	-
06.07.2017	9.50	6.33	-	-	-	-	-	-
16.07.2017	32.00	4.57	-	-	-	-	-	-
01.08.2017	15.00	25.71	2.10	4.30	6.70	6.9	7	7.8
03.08.2017	18.50	24.67	5.30	8.00	9.70	10	9.9	11.6
04.08.2017	16.50	24.75	5.00	6.80	8.20	8.5	8.6	10.5
06.08.2017	19.50	26.00	6.30	10.10	11.70	11.6	12.3	13.2
13.08.2017	26.80	4.47	-	-	-	-	-	-
14.08.2017	10.50	12.60	-	-	-	-	-	-
17.08.2017	18.50	20.18	5.10	6.20	9.00	9.3	9.4	10
19.08.2017	25.00	25.00	13.00	15.20	17.10	17.5	16.8	17.7
Total	213.80		36.80	50.60	62.40	63.80	64.00	70.80

-: No macroscopic surface runoff.

surface runoff was collected using a V-shaped PVC structure. A 500-ml of collected runoff water was sampled and filtered by 0.45μm fiber filters. The water samples were kept at -4°C prior to chemical analysis in the lab. We used the stand phosphomolybdate blue method to determine the concentrations of DIP [18]. For DTP concentration, the samples firstly digested by via acidic persulfate and then used the same method with DIP to measure. For DOP concentration, we calculated by difference between DTP and DIP.

Data analyses

For all statistical tests were carried out using SPSS.19 and Microsoft Excel 2016 software. The statistical difference used the least significant difference (LSD) test at the PB5% level.

Result and Discussion

Surface runoff and P loss characteristics at the agricultural field scale

A total of 12 rainfall events coourred during the field investigation from June to September. The precipitation ranged from 9.50mm to 32.00mm with rainfall intensity varying from 4.47 to 26.00 mm/h (Table 4). Only those rainfall events, with the precipitations intensity being over from 20.18 to 26.00 mm h^{-1}, produced the surface runoff from agricultural fields. Overall, the carrot field had the largest discharge 70.80 mm, following was cabbage, verdant, ginger, maize and peanut during the year 2017 (Table 4). The surface runoff depthes ranged from 62.40 to 70.80 mm for the vegetables fields, significant higher than these for the maize (36.80mm) and peanut (50.60mm) fields, suggesting fields with modern cropping systems produced larger volume of surface runoff than that of traditional cropping system under same precipitation conditions.

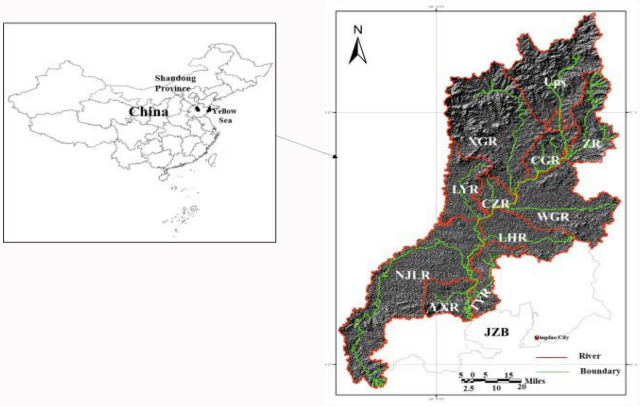

Figure 1: Site location and sub watersheds compositions of Dagu River watershed**.** Ups: upstream sub watershed, ZR: Zhu River sub watershed, CGR: Changguang River sub watershed, XGR: Xiaogu River sub watershed, WGR: Wugu River sub watershed, LYR: Luoyao River sub watershed, LHR: Liuhao River sub watershed, NJLR: Niaojiaolai River sub watershed, YNR: Yuunxi River sub watershed, TYR: Taoyuan River sub watershed, CZR: Chengzi River sub watershed.

There were significant variations in P concentrations in surface runoff for different agricultural fields (Table 5 and Table 6). The DTP concentrations ranged from 0.85 to 6.46 mg P L^{-1} for the peanut fields, 2.13 to 7.09 mg P L^{-1} for the maize fields, 9.43 to 11.18 mg P L^{-1} for the ginger fields, 5.48 to 10.22 mg P L^{-1} for the verdant fields, 7.18 to 17.74 mg P L^{-1} for the cabbage fields, 7.15 to 9.22 mg P L^{-1} for the carrot fields, respectively. Cabbage fields had the largest DTP concentrations, and followed by ginger, verdant, carrot, maize and peanut, with the concentration of 11.68 ± 3.46, 10.12 ± 0.67, 8.75 ± 1.53, 4.66 ± 4.91, and 4.54 ± 1.88 mg P L^{-1}, respectively (Table 6). Fields with modern cropping systems had significantly higher DTP concentrations in surface runoff water than these with traditional cropping systems.

DIP was the dominated form of DTP in surface runoff of traditional agricultural fields, accounting for about 74.2% and 86.5% of DTP for maize field and peanuts field, respectively. But for vegetable fields, DIP accounted for 58.20%, 47.23%, 63.52% and 25.03% of DTP, and DOP accounted for 41.76%, 52.73%, 37.48% and 74.97% of DTP for ginger, verdant, cabbage, and carrot, respectively (Table 6). DOP had higher percentages from vegetables fields than that from maize/peanut fields.

P losses from agricultural fields and sub-watershed

There were significant variations in P loses from agricultural fields with different cropping systems. The P losses ranged from 1.67 to 7.48 kg P hm^{-2}. The largest P losses were from cabbage field, followed by ginger fields (6.32 kg P hm^{-2}), carrot fields (5.88 kg P hm^{-2}), verdant

Table 5: P concentration in surface runoff of each crop field.

Precipitations mm	Tradition						Modern											
	Peanut mg P L^{-1}			Maize mg P L^{-1}			Ginger mg P L^{-1}			Verdant mg P L^{-1}			Cabbage mg P L^{-1}			Carrot mg P L^{-1}		
	DIP	DOP	DTP	DIP	DOP	DTP	DIP	DOP	DTP	DIP	DOP	DTP	DIP	DOP	DTP	DIP	DOP	DTP
15.00	0.47	0.38	0.85	3.26	0.65	3.92	5.44	5.44	10.89	2.92	7.30	10.22	5.40	7.02	12.42	1.79	5.36	7.15
18.50	2.54	0.25	2.79	2.11	0.02	2.13	5.59	5.59	11.18	2.88	4.60	5.48	14.54	3.20	17.74	2.40	6.20	8.60
16.50	3.53	2.93	6.46	3.71	1.81	5.53	6.01	3.78	9.79	5.64	2.82	8.45	3.87	5.04	8.91	1.60	6.30	7.90
19.50	4.90	0.98	5.88	2.77	0.83	3.60	5.89	3.54	9.43	4.64	3.25	7.88	7.68	4.61	12.29	2.50	5.00	7.50
18.50	3.65	0.60	4.25	2.93	0.35	3.28	6.62	3.97	10.59	3.18	5.27	8.45	9.06	5.43	14.49	1.89	7.33	9.22
25.00	3.25	1.31	4.56	6.69	0.40	7.09	5.79	3.80	9.59	4.23	5.56	9.79	4.79	2.39	7.18	2.08	6.89	8.97

Table 6: Flow - weight mean concentrations and loss flux of DTP in agricultural fields.

Crops		Surface Runoff mm	Concentration mg P L^{-1}			Loss flux kg P hm^{-2}	Average loss flux kg P hm^{-2}
			DIP	DOP	DTP		
Tradition	Peanut	36.8	3.37 ± 1.35 (74.23 %)	1.17 ± 4.54±1.88^{c}	4.54 ± 1.8^{8}c	1.67	2.01±0.34
	Maize	50.6	4.03 ± 1.47 (86.48 %)	0.63 ± 4.66±4.91^{c}	4.66 ± 4.9^{1}c	2.36	
Modern	Ginger	62.4	5.89 ± 0.37 (58.20 %)	4.23 ± 10.12±0.64^{ab}	10.12 ± 0.6^{7a}b	2.36	6.31±0.72
	Verdant	63.8	3.99 ± 1.01 (47.27 %)	4.77 ± 8.75±1.53^{b}	8.75 ± 1.5^{3}b	5.39	
	Cabbage	64	7.42 ± 3.58 (63.52 %)	4.25 ± 11.68±3.46^{a}	11.68 ± 3.4^{6}a	7.48	
	Carrot	70.8	2.08 ± 0.32 (25.03%)	6.23 ± 8.31±0.76^{b}	8.31 ± 0.76^{b}	5.88	

Flow-weighted mean (FWM) concentrations were calculated by dividing the cumulative P losses with the respective cumulative runoff volume; values for a parameter followed by the different letter within columns are statistically different at P<0.05 according to the Least Significant Difference test. (%) in DIP and DOP was the percentage in DTP.

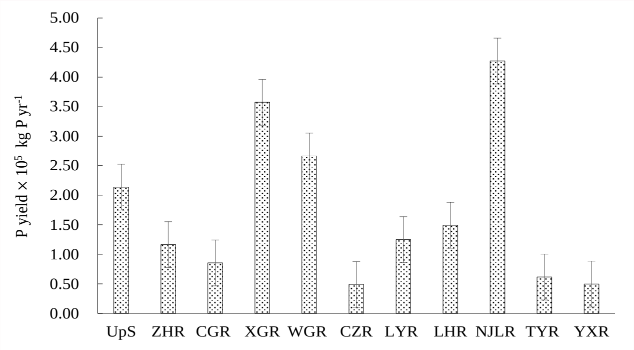

Figure 2a: Annual P losses from each sub watershed.

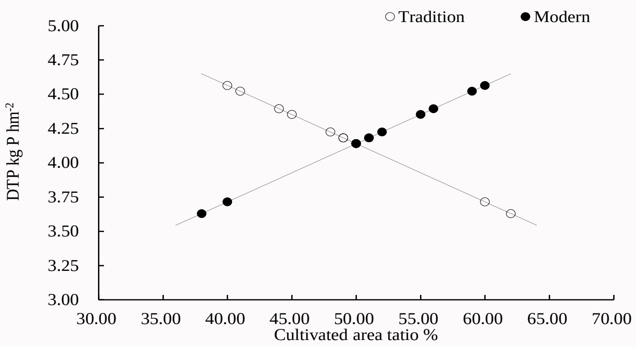

Figure 2b: Relationship between P yield and cropping system compositions in sub watersheds.

fields (5.39 kg P hm^{-2}), maize field (2.36 kg P hm^{-2}) and peanut field (1.67 kg P hm^{-2}). P losses from vegetable fields were significantly higher than that from maize and peanut fields. The average P loss was 6.31 ± 0.72 kg P hm^{-2} and 2.01 ± 0.34 kg P hm^{-2} between fields with modern cropping systems and fields with traditional cropping systems, respectively.

We expanded the P losses from fields to the sub-watersheds to provide the context for the sub-watershed yeilds of P loss via surface runoff (Figure 2a). The P yields from sub-watershed scale showed significant spatial patterns. NJLR yielded the largest DTP export, reaching 4.27 × 10^{5} kg P yr^{-1}; but the DTP yields were only 0.5 × 10^{5} kg P yr^{-1} for the YXR and CZR. Considering the area ratios of cropping system composition against total areas of each sub-watershed (Table 1), the P losses from unit agricultural land of sub-watersheds was from 3.63 to 4.56 kg P hm^{-2} yr^{-1} (Figure 2b). The P losses in unit agricultural land in each sub-watershed had a positive relationship with ratio of modern cropping systems and negative relationship with the ratio of traditional cropping systems (Figure 2b). This indicates that the increase in the cultivated area of modern cropping system would enhance the P loss at sub-watershed scale.

P losses from the whole watershed

When summed up to the whole watershed of Dagu river, the DTP losses were 18.61×10^{5} kg P yr^{-1} via the surface runoff from agricultural system. The traditional cropping system contributed 23.46 % and modern cropping systems contributed 76.54 % of DTP loss in the whole Dagu River watershed (Figure 5 and Table 1), which suggested that the modern cropping systems be the dominated DTP source in agricultural systems of Jiaozhou Bay watershed.

Conclusion

Under 12 rainfall events, the study clearly demonstrated that precipitation intensity was the dominated factor in surface runoff from agricultural fields in Dagu River watershed. Vegetables fields produced more surface runoff and higher DTP concentrations than that of traditional crops fields. For the P losses via surface runoff, DIP was the dominated loss form in traditional cropping system, while the

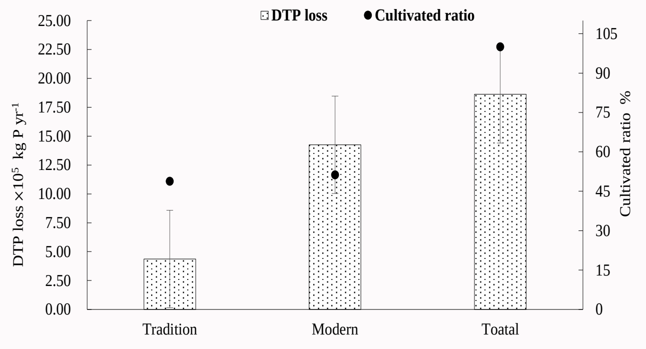

Figure 3: DTP loss flux from Dagu River watershed.

DOP had higher proportion of DTP from modern cropping systems. At agricultural field scale, modern cropping systems had higher DTP losses than that of traditional cropping systems. The spatial patterns of DTP losses at sub-watershed scale were impacted by the composition of cropping systems types. TDP yields at sub-watersheds scale had positive relationship with the cultivated area of modern cropping system and negative relationship with the cultivated area of traditional cropping system. Traditional cropping systems contributed 23.46% and modern cropping systems contributed 76.54% of DTP, respectively. Annual losses were 18.61 ×10^5 kg P of dissolved P from the whole Dagu River watershed. The change from traditional cropping systems to modern cropping systems can enhance the DTP losses form agricultural system.

Acknowledgement

This research was supported by the National Key Basic Research Program (973) of China (No.2015CB452901) and the National Natural Science Foundation of China (41371454). All raw data for this paper are properly cited and referred to in the reference list. The processed data, which were used to generate the figures, are available upon request to the corresponding author.

References

1. Cordell D, J-O Drangert and S White. The story of phosphorus: Global food security and food for thought. Global Environmental Change. 2009; 19: p. 292-305.
2. Tilman D. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. Proceedings of the National Academy of Sciences of the United States of America. 1999; 96: p. 5995-6000.
3. Bellarby J, et al. The stocks and flows of nitrogen, phosphorus and potassium across a 30-year time series for agriculture in Huantai county, China. Sci Total Environ. 2018; 619-620: p. 606-620.
4. Steen I. Phosphorus availability in the 21st century: Management of a non-renewable resource. Phosphorus Potassium. 1998. 217: p. 25-31.
5. Lou H, et al. Quantitative evaluation of legacy phosphorus and its spatial distribution. J Environ Manage. 2018; 211: p. 296-305.
6. Khan A, et al. Phosphorus efficiency, soil phosphorus dynamics and critical phosphorus level under long-term fertilization for single and double cropping systems. Agriculture, Ecosystems & Environment. 2018; 256: p. 1-11.
7. Dodd JR and AP Mallarino. Soil-Test Phosphorus and Crop Grain Yield Responses to Long-Term Phosphorus Fertilization for Corn-Soybean Rotations. Soil Science Society of America Journal. 2005; 69: p. 1118-1128.
8. Manschadi AM, et al. Reprint of "Developing phosphorus-efficient crop varieties—An interdisciplinary research framework". Field Crops Research. 2014; 165: p. 49-60.
9. Conley DJ and GE Likens. Ecology. Controlling eutrophication: nitrogen and phosphorus. Science. 2009; 323: p. 1014.
10. Paerl HW. Assessing and managing nutrient-enhanced eutrophication in estuarine and coastal waters: Interactive effects of human and climatic perturbations. Ecological Engineering. 2006; 26: p. 40-54.
11. Haygarth PM, AN Sharpley and AN Sharpley. Terminology for phosphorus transfer. Journal of Environmental Quality. 2000; 29: p. 10-15.
12. Smil V. PHOSPHORUS IN THE ENVIRONMENT: Natural Flows and Human Interferences. Annual Review of Energy & the Environment. 2000; 25: p. 53-88.
13. Jiao P, et al. Phosphorus loss by surface runoff from agricultural field plots with different cropping systems. Nutrient Cycling in Agroecosystems. 2010; 90: p. 23-32.
14. Carpenter SR, et al. Non-Point Pollution of Surface Waters With Phosphorus and Nitrogen. Ecological Applications. 1998; 8: p. 559-568.
15. Stutter M and S Richards. A novel approach to evaluating relationships between soil test and runoff P at landscape scales by integrating farmer knowledge on soil drains. Agriculture, Ecosystems & Environment. 2018; 254: p. 179-190.
16. Krutz LJ, MA Locke, and SR Jr. Interactions of tillage and cover crop on water, sediment, and pre-emergence herbicide loss in glyphosate-resistant cotton: implications for the control of glyphosate-resistant weed biotypes. Journal of Environmental Quality. 2009; 38: p. 1240.
17. Sims JT, et al. Managing agricultural phosphorus for environmental protection. 2005.
18. Murphy J and JP Riley. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta. 1962; 27: p. 31-36.