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To What Extent Can Complimentary Irrigation of Wheat with Wastewater, on Soils Along Belbais Drain, Affect the Plants?

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ABSTRACT

Water shortage is one of the important issues in the coming century. Thus, many countries are forced towards using non-conventional water sources such as wastewaters. Compared with fresh waters, treated wastewaters usually contain higher contents of plant nutrients. To assess the implications of using wastewater of Belbais drain for complimentary irrigations of wheat, ten locations along the drain were selected for water sampling. Soil and wheat samples were also collected from the nearby farms at the aforementioned locations. There were no specific trends or distribution patterns detected for contents of each of NO_3-N, P, B and As along the drain. NO_3-N in water had a slight to moderate degree of restriction on use. Also, P-content exceeded its normal range in irrigation water. In spite of that, contents of N and P in wheat were within the normal range in shoot and grain. Content of B in water had a slight to moderate degree of restriction on use, but plants did not exhibit B toxicity symptoms. Contents of As in water of many locations exceeded the permissible level of 0.1 mg As L^{-1}. Contents of As in soil (2.1 - 3.7 mg As kg^{-1}) did not exceed the permissible level of 10 mg kg^{-1}, but As in grains exceeded the permissible level of 1 mg kg^{-1} for food stuff. The calculated elemental grain/shoot ratio varied between 0.5439 and 0.8299. Individual practices of farmers on lands nearby Belbais drain are most certainly behind the increase in contents of the investigated elements in water of the drain. Efficient management of irrigation using wastewater of agricultural Drains in Egypt cannot be attained without increasing farmers' awareness of the negative aspects that may arise due to the unmanaged agricultural practices.
Keywords: Belbais drain; wastewater reuse, nitrate, phosphate, boron, arsenic

INTRODUCTION

Water shortage problem has become one of the important issues in the coming century (Macedonio *et al.*, 2012) threating food security (Stikker, 1998 and Seckler *et al.*, 1999). Accordingly, many countries were forced to use unconventional sources to satisfy their water needs (Angelakis *et al.*, 1999, OhIsson, 2000, Pereira *et al.*, 2002 and Bixio *et al.*, 2006). Among the various unconventional sources are wastewaters of agricultural drains (Angelakis *et al*., 1999,Chu *et al*., 2004 and Bixio *et al*., 2006). Treated wastewaters contain higher levels of plant nutrients compared to potable waters (Bernstein *et al*., 2009). Nutrients in treated wastewaters that are important to agriculture include nitrogen, potassium, zinc, boron and sulphur (Asano and Levine, 1998).

Nitrogen is the main nutrient limiting crop production (Fageria and Baligar, 2005). Commercial synthesis of N-fertilizers from N in the air is the most important for crop production (Haynes *et al.*, 1986). N_2-fixing bacteria can partially substitute inorganic N application (Scherer-Lorenzen *et al*., 2007 and Abbas *et al*., 2011). Amino acids and short peptides can be applied for certain plants as N-sources (Adamczyk *et al*., 2010). Excessive application of N causes overgrowth, delay maturity, and poor quality of crops (FAO, 1985) and can cause eutrophication of water bodies (Zhu *et al*., 2008).

Phosphorus is vital for crop production especially during the early stages of growth (Grant *et al*., 2005). It is mainly supplied to plants as mineral fertilizers derived from phosphate rock, which is a non-renewable resource and is estimated by Cordell *et al*. (2009) to deplete within 50–100 years. Treated wastewater is also a source of P but as N, its presence in excessive contents would cause eutrophication of water bodies (de-Bashan and Bashan, 2004).

Boron is an essential element for plant growth at low concentrations and its deficiency, in wheat, could be noticed in form of increases in number of open spikelets and decreases in number of grains per spike (Furlani et al., 2003). However, its excess is toxic to plants (FAO, 1985).

Arsenic is a phosphate analogue (Abedin *et al*., 2002) and has negative effects on plants (Abbas and Abdelhafez, 2013) and human health (Abdelhafez *et al*., 2014). It possess potential health threats in Sahl El-Hossainia ,Egypt (Abdelhafez *et al*., 2015) which is irrigated with the wastewater of Bahr Hadous drain mixed with fresh Nile water (Hafez, 2005) The Belbais drain, the main drain of Cairo, might contain high contents of arsenic in its water.

The current study aimed at investigating the consequences of using the water of Belbais drain for complimentary irrigations of wheat grown in soils nearby the drain in the North East region of Egypt. Wheat plants grown thereon seemed healthy with a relatively high productivity. Four elements were selected in the current study. They are three nutritional elements (nitrogen, phosphorus and boron) and a non-nutritional one (arsenic). These elements were determined in the Belbais drain water in different locations along the drain. Also, samples of soils and wheat plants were collected from the same locations for determination of the same elements.

MATERIALS AND METHODS

Area of study

Belbais drain is the main drain of waste water from Cairo (Taylor *et al.*, 1993) carrying sewage and industrial wastewaters (treated and untreated) for 60 km (Stahl *et al.*, 2009) and discharging the water into Bahr El Baqr drain (Lovelady *et al.*, 2009). Arable lands nearby the drain are mainly short of fresh water for their irrigation (Hamed *et al*., 2011) and frequently use the drain's water for complimentary irrigation (Pereira *et al*., 2002 and Ibrahim *et al*., 2016). Ten locations along the drain of Belbais were selected for water sampling as shown in Figure 1.Soil and wheat samples were also collected from the arable lands at the aforementioned locations to investigate the implications of using such water for complimentary irrigations on accumulation of NO_3-N, P, B and As in soils and the above-ground plant parts.

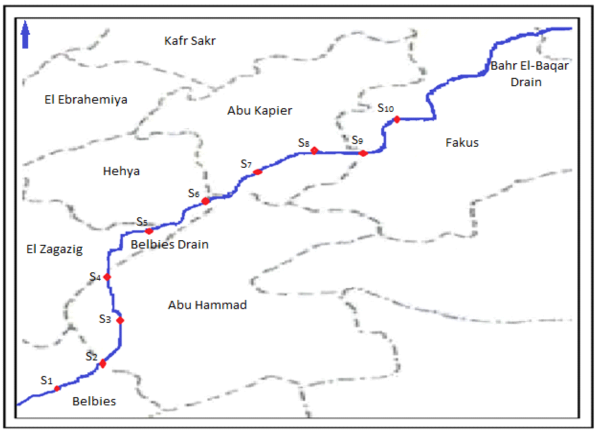

Fig 1. Location description and site sampling

Soil, water and plant preparation and characteristics

Water samples were analyzed for their chemical properties using methods cited by Chapman and Pratt (1961) and Page *et al.* (1982) and the results are presented in Table 1.

Table 1.Chemical properties of Belbais drain water

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
pH	7.4	7.5	7.3	7.4	7.2	7.5	7.4	7.5	7.3	7.1
EC, dS m^{-1}	1.7	1.5	1.7	1.6	1.5	1.5	1.8	1.7	1.7	1.8
SAR	4.2	4.1	3.9	3.9	4.0	5.1	5.3	4.1	4.5	4.3

L1.. to…L10 are locations 1 to 10 investigated along the Belbais drain ;SAR: Sodium Adsorption Ratio

Soil samples were air dried, crushed and sieved to pass through a 2 mm mill. Chemical and physical properties of the investigated locations were determined according to Klute (1986) and Page *et al.* (1982) and the results are presented in Table 2.

Table 2. Chemical and physical properties of the investigated locations

Site*	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
EC**(dS m^{-1})	1.4	1.8	8.3	2.0	1.6	1.8	1.8	1.5	2.0	2.3
pH***	7.3	7.3	7.2	7.2	7.4	7.3	7.2	7.4	7.2	7.4
$CaCO_3$ (g kg^{-1})	33.9	31.4	36.5	30.2	29.7	30.0	24.2	33.3	30.1	29.5
OM (g kg^{-1})	14.1	20.0	12.4	18.1	13.9	11.8	13.2	20.4	15.6	16.4
Particle size distribution and soil texture										
Sand, %	40.1	36.3	31.2	27.5	28.4	29.5	28.9	26.8	29.1	27.0
Silt, %	40.2	43.6	49.1	48.5	49.6	50.3	52.3	50.8	55.1	51.3
Clay, %	19.7	20.1	19.7	24.0	22.0	20.2	18.8	22.4	15.8	21.7
Texture (International)	CL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL	SiCL

*** See footnotes of Table 1 - **EC of soil paste extract - ***pH in 1:2.5 w:v (soil:water) suspension**

Plant samples were washed with tap water, then deionized water , separated into straw and grain, oven dried at 70 C for 48 h and then ground to pass through a 5mm sieve.

Soil, water and plant analysis

Soil samples were acid digested in a block digester using a mixture of H_2SO_4 (conc.) and H_2O_2 (conc.) according to Buondeonno et al. (1995). Plant samples were acid digested according to Peterburgski(1968). N-contents were determined in the digests of soil and plant as well as in the wastewater samples using Kjeldahl method (Page et al., 1982). Phosphorus was determined in the wastewater, digests of soil and plant according to the phospho-molybdate-vanadate method (Gupta et al.,1993) and measured spectro-photometrically. Boron and As were measured in the wastewater, digests of soil and plant using ICP-MS

RESULTS AND DISCUSSION

- **Elements in the wastewater of Belbais drain**

Analysis of variance shows that wastewaters collected from the studied locations varied significantly in their contents of NO_3-N, P,B and As (Table 3). It is necessary to follow up the changes that occurred in concentrations of the investigated elements along the drain to determine whether these concentrations followed a definite distribution pattern by either increasing or decreasing along the drain. This might explain the behavior of these elements in soils of the nearby farms. A distribution pattern of increase in concentrations along the drain probably indicates that the wastewater, which already contains high concentrations of the studied elements, would receive further quantities of these elements from the nearby farms through leaching, while a distribution pattern of a decrease in concentrations of these elements probably indicates that these elements accumulate at high concentrations in soil sediments of the nearby arable lands.

Significant variations in concentrations of NO_3-N, P, B and As were detected in the wastewater of Belbais drain from location 1 to 10 (Figures 2 and 3). In spite of that, there were no concentration trends or distribution patterns detected for the four investigated elements along the drain i.e. concentrations of these elements did not follow either an increase pattern or a decrease one along the drain. Such a result supports an assumption that the agricultural practices in the arable lands surrounding the drain may have relatively higher impacts on accumulation of elements in soils and within the grown plants than their concentrations in the wastewater.

Table 3. Analysis of variance for the concentrations of NO_3-N, P,B and As in the wastewater collected from the different locations along the drain

Source	Nitrogen					Phosphorus				
	DF	SS	MS	F	P	DF	SS	MS	F	P
Location	9	550.22	61.14	440.76	<0.001	9	10.065	1.12	262.72	<0.001
Error	20	2.77	0.139			20	0.0855	0.004		
Total	29	443.00				29	10.15			
	Boron					Arsenic				
Location	9	3.59	0.40	102.61	<0.001	9	0.23	0.003	162.99	<0.001
Error	20	0.078	0.004			20	0.0003	0.00001		
Total	29	3.67				29	0.024			

- **Nitrogen and phosphorus in the wastewater of Belbais drain**

The highest concentration of NO_3-N in wastewater was detected at location 2; whereas, the highest concentrations of P were found at locations 1 and 10 , and P decreased in between these locations. The NO_3-N in wastewater exceeded the safe range of 0-10 mg L^{-1} in irrigation water with a slight to moderate degree of restriction on use (5- 30 mg L-1) according to FAO (1994). P-content in the wastewater exceeded its safe range in irrigation water (0-2 mg L-1). Although, managing such wastewater may have beneficial effects on plant because of its high contents of N and P , excessive use of it with unmanaged irrigation system would cause adverse effects on the ecosystem. Efficient management of irrigation water is vital for avoiding contamination of surface water with nitrogen (Diez et al., 2000; Spalding *et al*., 2001; Cavero et al., 2003; Zotarelli *et al*., 2009).

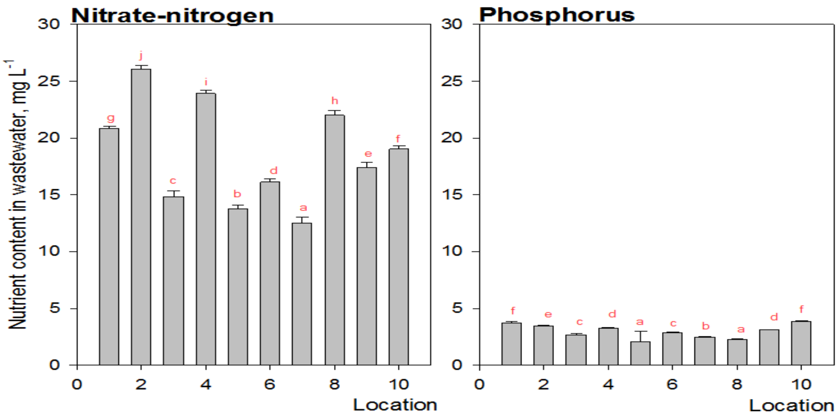

Fig 2. Nitrate-nitrogen and P - concentrations in the wastewater along the drain of Belbis

2. Boron and arsenic in the wastewater of Belbais drain

The highest concentration of B in wastewater was detected around location 5 ; whereas, the least concentration was found at location 9. Boron concentrations in wastewater had a slight to moderate degree of restriction on use (0.7-3 mg L^{-1}) according to FAO (1994). On the other hand, the highest concentrations of As in wastewater of Belbais drain were in location 4. Although the concentrations of As in wastewater seemed relatively low, they exceeded, in many locations, the permissible level of 0.1 mg As L^{-1} in irrigation water suggested by FAO (1992) and Rahaman *et al*. (2013). Therefore, using such water for irrigation purposes might possess a serious threat to animals and individuals feeding on plants grown in these areas.

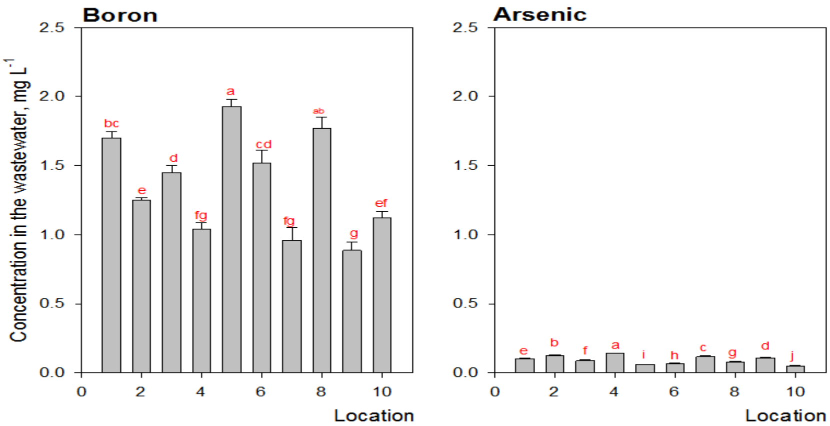

Fig 3. Boron and arsenic concentrations in the wastewater along the drain of Belbis

- **Elements in soil**

Analysis of variance revealed that total contents of the investigated elements i.e. NO_3-N, P, B and As changed significantly among the different locations along the drain (Table 4).

Table 4. Analysis of variance for the concentrations of total N, P,B and As in soil irrigated with the wastewater of Belbais drain

Source	Nitrogen-Nitrate					Phosphorus				
	DF	SS	MS	F	P	DF	SS	MS	F	P
Location	9	1141.39	126.82	366.24	<0.001	9	20.50	2.28	351.43	<0.001
Error	20	6.93	0.35			20	0.13	0.007		
Total	29	1148.32				29	20.63			
	Boron					Arsenic				
Location	9	8.32	0.93	154.56	<0.001	9	0.41	0.05	394.04	<0.001
Error	20	0.12	0.006			20	0.002	0.0001		
Total	29	8.44				29	0.41			

- **Nitrogen and phosphorus in soil**

Nitrate-nitrogen and phosphorus varied significantly among soils at different locations along the drain (Fig 3) The highest concentration of NO_3-N was detected at locations 2 , whereas, the highest concentration of P was found at location 1. Concentrations of these nutrients did not follow any distribution pattern along the drain of Belbais.

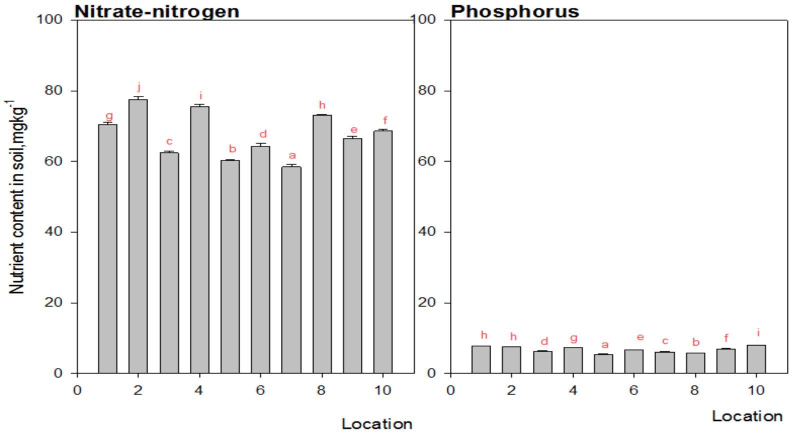

Fig 4.Nitrate-nitrogen and phosphorus in soils nearby Belbais drain

2. Boron and arsenic in soil

Although, there were slight variations in concentrations of the investigated elements among the different locations; however, such differences were significant (Fig. 5). The highest concentrations of B in soil were found at the fifth and the seventh locations; whereas, the highest concentrations of As were found at the second and the fourth locations. Generally, concentrations of As did not exceed the permissible level of 10 mg kg^{-1} reported by Basta *et al.* (2002). Neither did soil-As exceed the thresholds of 5 mg kg^{-1} in Finnish soils or 12 mg kg^{-1} in Canadian soils reported by Teaf *et al.* (2010).

- **Elements in the aboveground tissues of the cultivated wheat plants**

Analysis of variance shows that N, P, B and As in shoots and grains of wheat plants varied significantly among the locations (Table 4).

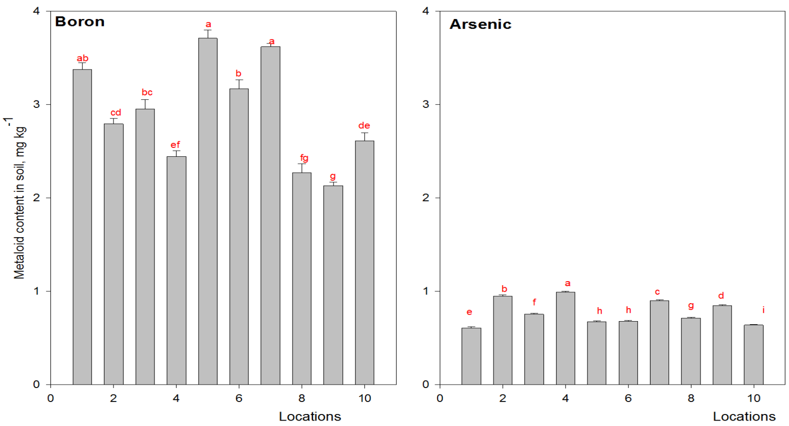

Fig 5.Boron and arsenic in soils nearby Belbais drain

Table 4. Analysis of variance for the concentrations of NO_3-N, P, B and As in wheat plants collected from different locations across Belbais drain

Source	DF	SS	MS	F	P	DF	SS	MS	F	P
Shoot										
	Nitrogen					**Phosphorus**				
Location	9	155.42	17.27	225.13	<0.001	9	0.09	0.0099	359.45	<0.001
Error	20	1.53	0.08			20	0.0006	0.0003		
Total	29	156.95				29	0.09			
	Boron					**Arsenic**				
Location	9	21.85	2.43	462.52	<0.001	9	8.97	0.996	130.42	<0.001
Error	20	0.11	0.005			20	0.15	0.008		
Total	29	21.96				29	9.12			
Grain										
	Nitrogen					**Phosphorus**				
Location	9	99.37	11.04	497.36	<0.001	9	0.046	0.005	221.98	<0.001
Error	20	0.44	0.02			20	0.0005	0.00002		
Total	29	99.82				29	0.046			
	Boron					**Arsenic**				
Location	9	48.58	5.40	560.15	<0.001	9	6.96	0.773	216.33	<0.001
Error	20	0.19	0.01			20	0.07	0.004		
Total	29	48.77				29	7.03			

- **Nitrogen and phosphorus in wheat**

Concentrations of nitrogen and phosphorus varied significantly in shoot and grain of wheat plants collected from different locations (Fig 6).The highest nitrogen contents in wheat shoot and grain were detected at location 2 , whereas, the highest phosphorus contents in shoot and grain of wheat plants were detected at location 10. However, these concentrations were within the normal ranges of N and P in wheat shoot (Korzeniowska, 2008).

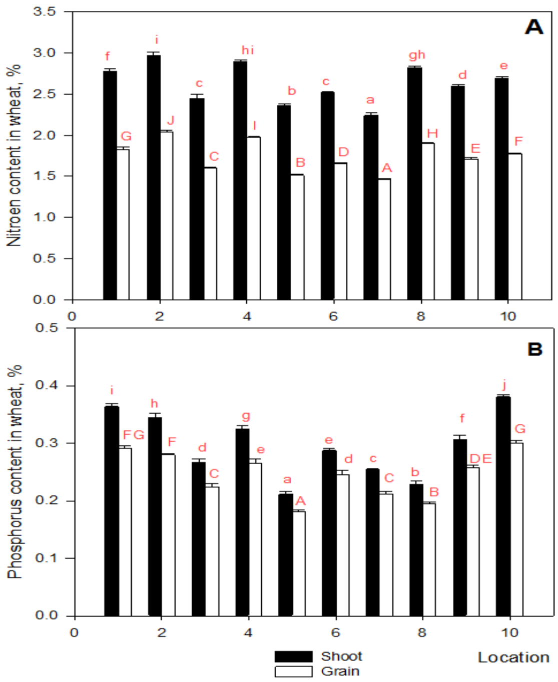

Fig 6. Nitrogen and phosphorus in the aboveground wheat parts

- **Boron and arsenic in wheat**

Concentrations of B and As varied significantly in shoot and grain of wheat plants collected from the locations; however such variations did not follow any distribution trend (Fig. 7). The highest concentrations of B in shoot and grain took place at location 5; whereas, the highest As in shoot and grain took place at location 4.

Symptoms of B toxicity could be observed on wheat shoot (Grieve and Poss, 2000) when B exceeds 44 mg kg^{-1} (Furlani *et al.*, 2003). The results obtained herein indicate that B-concentrations in wheat shoot were much lower than 44 mg kg^{-1} . Therefore, wheat plants did not suffer from B toxicity. On the other hand, As in grains exceeded the permissible level of 1mg kg^{-1} for food stuff (Liu *et al.*, 2012). A dietary intake of food stuff highly contaminated with As would cause negative implications on human health (Smith *et al.*, 2008). Thus, wheat grains collected from the area of study are not suitable for humans.

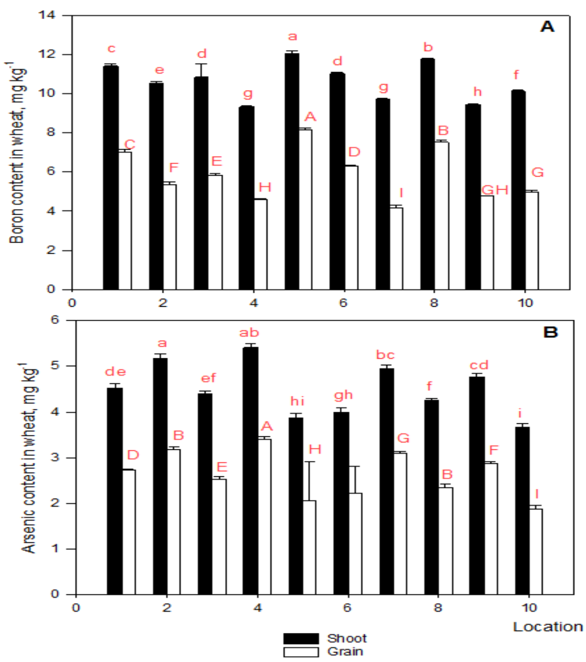

Fig 7. Boron and arsenic contents in the above ground wheat parts

The ratio between concentrations of the investigated elements in grains to the corresponding ones in shoots was calculated and the results are presented in Fig 8. Elemental gain/shoot ratio varied between 0.5439 and 0.8299. This ratio therefore can be used as an indicator to illustrate the ease by which an element such as those studied therein can transfer from shoots to roots. Probably, values of more than 0.5 are indicators of relatively high translocations of the investigated elements from shoot to grain.

Soil-water-plant relationships

Table 5 reveals that N and P contents in shoot and grain of wheat significantly positively correlated with contents in each of the soil and water. Also, significant positive correlations occurred between N and P contents in water and their corresponding ones in soils. Likewise, As and B contents in shoot and grain significantly positively correlated with their corresponding contents in soil and water. Such a result indicates that accumulation of these elements in soil led to consequent increases in their contents in wheat shoots and grains and had further impacts on contaminating the wastewater coming from Cairo. Nitrate is expected to leach out of the soil at rates exceeding the crop requirements (Di and Cameron, 2002; Ju *et al.*, 2006).

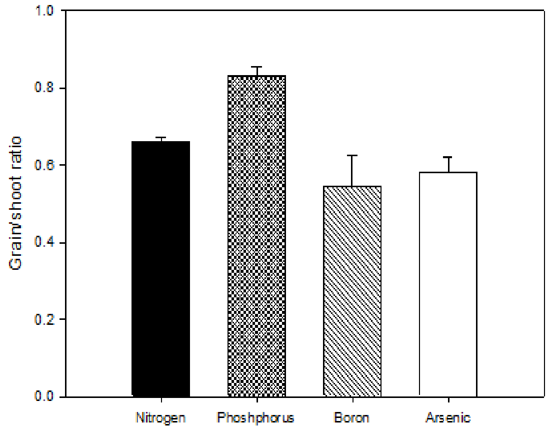

Fig 8.Elemental grain/shoot ratio of absorbed elements in wheat plants grown in the arable lands irrigated with the wastewater of Belbais drain.

Table 5.Soil-water-plant correlations of N, P, B and As

		Nitrogen				**Phosphorus**	
	Water	**Soil**	**Shoot**		**Water**	**Soil**	**Shoot**
Soil	0.992***			Soil	0.986***		
Shoot	0.983***	0.983***		Shoot	0.990***	0.992***	
Grain	0.992***	0.996***	0.987***	Grain	0.985***	0.993***	0.986***
		Boron				**Arsenic**	
	Water	**Soil**	**Shoot**		**Water**	**Soil**	**Shoot**
Soil	0.383*			Soil	0.978***		
Shoot	0.985***	0.377*		Shoot	0.981***	0.980***	
Grain	0.969***	0.290	0.972***	Grain	0.989***	0.983***	0.983***

In conclusion, a hypothesis that individual practices of farmers on arable lands nearby Belbais drain is among the main causes for increasing levels of N,P,B and As in the wastewater of Belbais drain. The main problem arises there is that the nearby farms use this water for complimentary irrigations. Consequently, the cycle of the studied elements seemed to follow a closed system. Thus, managing wastewater to increase the water budget in the North East region of Egypt cannot be attained without increasing the awareness of farmers about the negative aspects that may arise due to the unmanaged agricultural practices.

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إلي أي مدى يمكن أن يؤثر الري التكميلي بالمياه العادمة علي نباتات القمح النامية في الأراضي على امتداد مصرف بلبيس؟

محمود عبد الله علي ، أبو النصر هاشم عبد الحميد ، إيهاب محمد فريد ، محمد حسن حمزة عباس و حسن حمزة عباس
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أصبحت مشكلة نقص المياه احدى القضايا الهامة في القرن القادم التي تواجه العديد من البلدان ، مما دفعها إلي استخدام مصادر مياه غير تقليدية لزيادة كميات المياه المتاحة لديها مثل إعادة استخدام المياه العادمة ، ومثل هذه المياه العادمة تحتوي حتي بعد معالجتها على العديد من المغذيات بمستويات تفوق تلك الموجودة في مياه الري التقليدية، وبالتالي يهدف هذا البحث إلى دراسة تداعيات استخدام المياه العادمة من مصرف بلبيس للري التكميلي لنباتات القمح المزروعة في اراضي منطقة شمال شرق الدلتا، حيث تم اختيار عشرة مواقع للدراسة على طول مصرف بلبيس، وتم جمع عينات من المياه العادمة عند تلك النقاط، كما تم جمع عينات تربة من الأراضي المجاورة لها بالإضافة إلي عينات من القمح النامي في تلك المناطق، واوضحت النتائج عدم وجود أنماط محددة لتوزيع تركيز العناصر الأربعة موضع الدراسة على طول مصرف بلبيس، وبالنسبة لـ NO_3-N فدرجته في المياه العادمة تراوحت من خفيف إلى معتدل من حيث درجة القيد على استخدامها في الري، أيضا تجاوز محتوى الفوسفور بتلك المياه المدى المعتاد ، وعلى الرغم من ذلك، فكانت تركيزات N و P ضمن المستويات الطبيعية في الجزء الخضري والحبوب لنبات القمح، وقد كانت درجة البورون في المياه العادمة خفيفة إلى معتدلة من حيث درجة القيد علي استخدامها؛ من جهة اخري فإن النباتات النامية لم يظهر عليها أي اعراض سمية بالبورون، واكدت النتائج علي أن تركيزات الزرنيخ، في العديد من المواقع علي امتداد المصرف، قد تجاوز المستوى المسموح به لمياه الري (0.1 ملجم لتر$^{-1}$). بينما لم يتجاوز تركيزه في التربة المستوي المسموح بها (10 ملجم كجم$^{-1}$)، ولكنه تعدي المستوى المسموح في الحبوب (1ملجم كجم$^{-1}$)، وقد تراوحت نسب العناصر المحسوبة في الحبوب إلي تلك في الجزء الخضري من 0.5439 إلي 0.8299، وبالتالي يمكن استنتاج أنر الممارسات الفردية للمزارعين في الأراضي القريبة من مصرف بلبيس قد تكون هي المصدر الرئيسي لزيادة مستويات العناصر موضوع الدراسة في مياه المصرف، ومن ثم لا إضافة المياه العادمة لمصرف بلبيس كمصدر امن للري التكميلي دون زيادة وعي المزارعين للحد من الجوانب السلبية التي قد تؤثر علي نوعية مثل هذه المياه، بل على النظام البيئي بأكمله.

الكلمات الداله: مصرف بلبيس، اعادة استعمال المياه العادمة، النترات، الفوسفات، البورون، الزرنيخ.