Assessment of use of reclaimed water in unrestricted agriculture in Jordan Valley in the light of the new WHO Guidelines*

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The presence of *E. coli* in a water sample will often (but not always) mean that other excreta-related pathogens are also present. However, it is easier to measure *E. coli* concentrations and assume that it represents a group of similar pathogens than to measure concentrations of individual pathogens. *E. coli* is one type of fecal coliform which is present in large numbers in the feces and intestinal tracts of humans and other warm-blooded animals, and can enter water bodies from human and animal waste. Fecal coliform by themselves are usually not pathogenic. Four types of biological health risks associated with use of treated wastewater viruses, bacteria, protozoa, and intestinal nematode.

WHO-FAO-UNEP in their guidelines for the safe use of wastewater in agriculture, mentioned that even partially treated wastewater can be used for irrigation safely if multiple barriers approach is in place. This approach combines treatment and post-treatment barriers. The rationale for this flexibility is due to the understanding of socioeconomic status of developing countries and the dire need to exploit treated wastewater in dry countries. However, the use of partially treated wastewater should not compromise the health of people and to this end the stringent health-based target was the base for promoting the multiple barriers approach. WHO has determined that a disease burden of 1×10^{-6} DALYs (disability adjusted life year) per person per year from a disease caused by either a chemical or infectious agent is a tolerable risk for drinking water (WHO, 2004). The same stringent target DALY $1x10^{-6}$ is proposed to be applied in case of using wastewater for irrigation, because people assume that their food should be as safe as drinking water. $1x10^{-6}$ DALY means not more than 1 man loss per year per 1 million persons as a result of diseases arises from using treated wastewater in irrigation. To reach this stringent target a combination of treatment and non treatment options should be considered and implemented.

DALY concept is a metric unit for measuring a disease burden and it integrates both years of life lost as result of immature mortality and years of disability as a result of morbidity. For example in the developing countries DALY loss per case of diarrhoeal disease associated with the use of wastewater is $2.6x10^{-2}$ pppy . This number is equivalent to 38 cases per year per one million people. From DALY, two other terms are derived; tolerable disease risk and tolerable infection risk. The difference between the two terms lies in the fact that not all persons who are subjected to disease risk would surely develop clinical disease due to different reasons among which the difference in the immune systems. Tolerable infection risk is very important because from this figure, we can derive the acceptable wastewater quality through quantitative microbial risk assessment (QMRA). WHO guidelines, and based on DALY $1x10^{-6}$ consider the tolerable infection risk is 10^{-3}. According to the new WHO Guidelines, the required wastewater quality for unrestricted irrigation that meet the set tolerable infection risk is ($\leq 10^4$ FC/100 ml) which is equivalent to 4 log unit reduction from 10^8 (fecal coliform in raw

* Guidelines for the Safe Use of Wastewater, Excreta and Greywater, Volume 2; Wastewater use in agriculture, World Health Organization (WHO), 2006.

wastewater) to 10^4. WHO guidelines require 6 to 7 log unit reductions on fecal coliform counts (*E. coli is indicator*) from the source of wastewater and right prior crop consumption to meet 10^{-3} tolerable infection risk and hence additional 2 to 3 log unit reductions are needed to fully meet the requirements. These 2 to 3 log unit reductions should be realized by post-treatment options (measures) like storage of wastewater in reservoirs, drip irrigation barrier, natural decay of pathogen (Die off) and washing and peeling of the produce.

WHO guidelines call for less stringent target than the proposed one 1×10^{-6} DALY if the treatment options are not available or not effective, in this case two DALY targets can be applied in unrestricted agriculture; $1x10^{-5}$ DALY for field workers and $1x10^{-6}$ DALY for consumers. The application of $1x10^{-5}$ DALY for field workers means acceptance of using partially treated wastewater ($\leq 10^5$ FC/100 ml) with only 3 log unit reductions through treatment process but this requires additional 3-4 log unit reductions as post-treatment measures and before crop consumption to meet the $1x10^{-6}$ DALY for consumers. Interestingly, 2-3 log unit reduction through treatment process (10^5 FC/100 ml to10^6 FC/100 ml) is according to WHO recommendations enough to protect field workers.

Assessment of existing health protection barriers in upstream and downstream of KTR under common farming practices.

Tracking the contamination levels of pathogens along the food production chain, starting from pre-treatment process of wastewater, passing across the different barriers and ending at consumer's table, is the first required step in risk assessment and management. As a preliminary step for having a comprehensive and state risk assessment and management system in Jordan that covers all areas where treated wastewater is used for irrigation, a pilot risk system will be developed and implemented in upstream and downstream of KTR (Kherbit Assamra to KTR to Jordan Valley and finally to the consumer).

Based on the results of the following monitoring programmes which are implemented by different governmental institutions, compliance or no-compliance with WHO recommendations can be assessed.

- Results of the state irrigation water quality monitoring programme for the last 10 years
- Results of state crop monitoring programme for fresh vegetable produced on reclaimed water for 4 years
- Assessment of the field staff of the impact of farmer practices. Table (1) summarizes these monitoring programmes, the responsible institutions and the tested parameters

Table (1): Running monitoring programmes for treated wastewater uses in upstream and downstream of KTR

Programme	Institutions	Parameters and tests
Irrigation water quality	JVA and RSS	Physical, chemical and biological parameters
Soil, water ponds and ground water	JVA and WAJ	Chemical and biological parameters
Crop monitoring	JFDA	Biological ,nitrate and heavy metals
Health status monitoring	MoH	Communicable disease
Farmers practices	GTZ Reuse Project	Agricultural practices

The integration of the monitoring programmes results provides evidences of compliance or non-compliance of the existing system with the suggested health-based targets.

The following hazard barriers are available within the system which serves in reducing the risk for exposed people.

At local community level:

Treatment Plant	Water Storage	Access to safe drinking water and sanitation

At field workers and farmer level:

Treatment Plant	Water Storage	Access to safe drinking water	Personal hygiene (Relative)

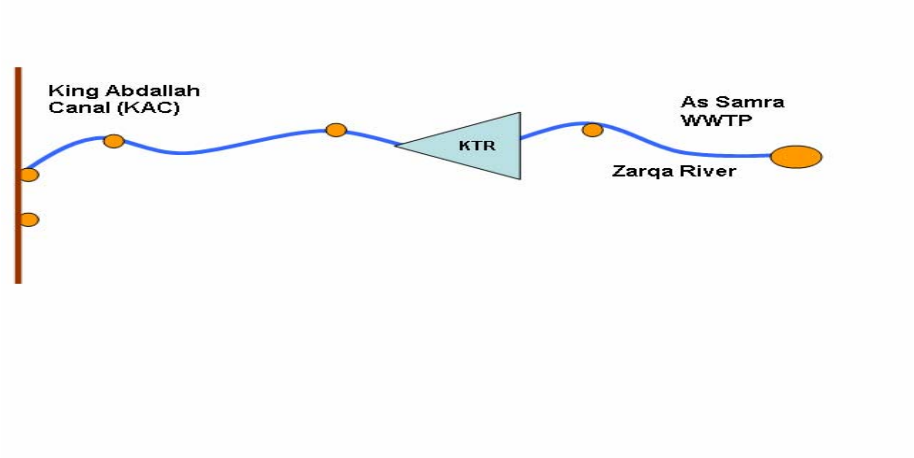
At consumer level:

Treatment Plant	Water Storage	Application techniques (Drip irrigation)	Natural Die off	Food Hygiene

According to WHO Guidelines, the required pathogens reduction in order to achieve the health-based target for safe use of treated wastewater in agriculture is 6-7 log unit reduction for consumers and 2-3 log unit reduction for fieldworkers. In other words, since bio-contamination level in raw wastewater estimates (10^8 FC/100 ml), 6-7 log unit reduction is needed to reach level 10^2-10^1 on the final produce, depending on the produce irrigated with such water. 7 log unit reductions are required for root crops, whereas 6 log unit reductions are enough in case of other eaten fresh crops. Annex (1) represents rapid assessment of Jordan status of reclaimed water (RW) use in agriculture in light of WHO Guidelines and prevailing farming practices. To make traceability of bio-contamination levels simple and understandable, the food production chain is divided into separated stages as follows:

Stage 1: From wastewater treatment plant to farm

1. **Treatment Plant**
   Table in Annex (1) shows that a considerable reduction in wastewater-related pathogens occurs as wastewater undergoes treatment process at WWTP. This reduction varies between 2-6 log unit reductions depending on potential efficacy of WWTP. For instance, in Assamra Plant (after rehabilitation), is the main source of irrigation water downstream KTR where reduction in pathogens reaches 6 log reduction units. As is the case, this barrier (Assamra Plant) can alone bring in the required pathogens reduction to meet the health-based target set in WHO Guidelines. Due to re-contamination, effluent of treatment plant ends in KTR, at relatively elevated level of biological contamination in an average range 10^3-10^4 ($\leq 10^3$ -10^4 FC/100 ml). The reason for this rise is the occurrence of continuous recontamination along Wadi Al Zarqa', while the effluent is flowing from Assamra to King Talal Reservoir (KTR).



Flow of treated wastewater from the source (WWTP) into Zarqa river then into KTR until it ends into King Abdullah Canal

2. **Storage in the Reservoir (Post-treatment barrier)**
   Retention period (withholding) of irrigation water in KTR adds at least 1 log unit reduction in pathogens level and thus the bio-contamination of water leaving KTR to downstream becomes 10^1 to 10^2 ($\leq 10^1$ -10^2 FC/100 ml). Later, water exposes to rise in bio-contamination level reaching 10^3-10^4 ($\leq 10^3$ -10^4 FC/100 ml) due to trash disposal practices from the local communities living near the canal.

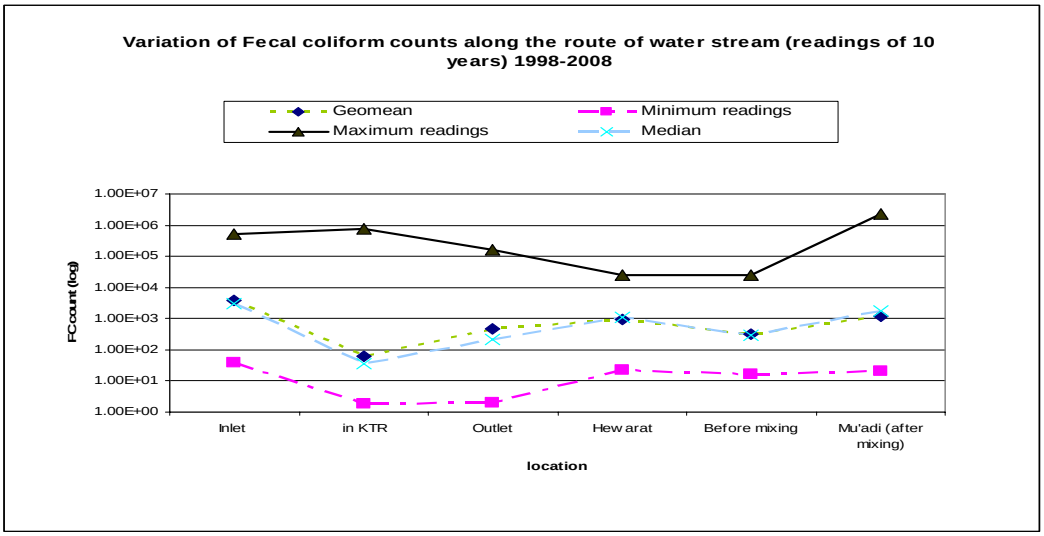


Figure1: Variation in biological contamination level across the route of irrigation water stream (RSS 1998-2008

Figure (1) shows the results of 10 years monitoring for irrigation water quality along the route of treated wastewater just before water enters into KTR and prior it reaches the farms in the Jordan Valley. The geometric means for fecal coliform counts for all locations are confined to the range10^1 to 10^3 with the lowest figure when treated wastewater is stored in KTR and the highest before it enters into KTR. The impact of KTR on water quality is obvious. Figure (2) shows number of samples with different fecal coliform counts. It is obvious that number of samples exceeds 10^5 is very low and it ranges from 0 to 3 out of an average 120 readings. As for samples between 10^3 and 10^5 the figure shows high numbers and in all locations which provide an evidence that the limit proposed in old WHO guidelines (($\leq 10^3$ FC/100 ml) is frequently exceeded.

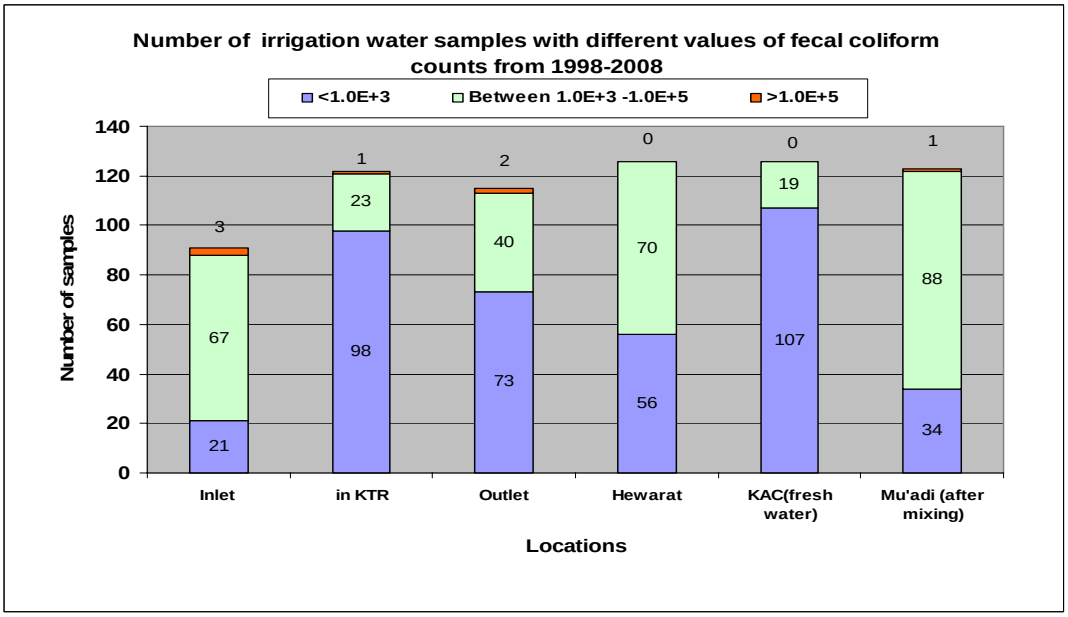


Figure2: Numbers of water samples with values of fecal coliform less than 10^3, between 10^3 and 10^5 and higher than 10^5

It is worth to mention that results of intestinal nematodes are always in compliance with the suggested values of the new WHO guidelines.

Stage 2: On farm

Owing to disparity in risk of contamination on different crops produced on RW, these crops have been categorized into three distinctive categories according to WHO Guidelines:

- Vegetable crops: comprise wide range of crops like tomato, cucumber, eggplant, squash, etc. and require 6 log unit reductions.
- Leaf crops: which are fresh eaten, comprise lettuce, parsley, rocket and etc and require 6 log unit reductions.
- Root crops: which are fresh eaten, comprise carrot, green onion, radish and etc and require 7 log unit reductions.

On farm level, additional pathogens reduction barriers take place. These barriers include:

1. **Drip irrigation system barrier (Post-treatment barrier)** which, according to WHO Guidelines, can bring in an additional 2-4 log unit reduction depending on nature of the crops. The 2 log unit reduction can be achieved for low-growing crops (leaf crops), whereas 4 log unit reduction is reported for high-growing crops (other vegetable crops). Such reduction is not possible for root crops due to their growth nature under soil surface that keep them in direct contact with soil and irrigation water as long as it remains in the soil. In Jordan drip irrigation is a common practice for the majority of farmers. In the Jordan Valley 90% of farmers use drip irrigation. This should be taken into consideration when setting the appropriate the health-based target for farmers and farm workers ($1x10^{-5}$ instead of 10^{-6}). The exposure of both farmers and farm workers from direct contact to low-quality irrigation water is far less in case of drip irrigation compared to surface irrigation provided that certain wrong practices like using irrigation water for washing stopped.

   Still, there is a very wrong and bad practice in Jordan Valley, the use of unfermented manure which poses high risk of cross-contamination; therefore, efforts should be excreted in this field either to prohibit use of unfermented manure or to secure good management practices for fresh manure uses.

2. **Natural pathogens die-off (Post-treatment barrier)** can play significant role in bringing in significant reduction to these pathogens as result of desiccation, sun radiation, high temperature which could reach 2 log unit reductions per day from last irrigation to harvest time. The climatic conditions in Jordan (high temperatures and abundant sunshine year-round) favor high decay of pathogens; however, in this assessment the contribution of this barrier was assessed to be only 1 log unit reduction to be in the safe side. Natural die-off for root crops has been ignored due to its growth nature.

It deserves to mention that certain harvested crops will be subjected to recontamination risk in case farmers wash their harvest with RW. Such practice is common in case of leaf crops and root crops where some farmers use it either to maintain fresh looking for leaf crops (moistening crops to prevent withering) or to get ride of mud and soil particles on root crops before sending it to market. As is the case, such scenario, if happens, should be taken into account. This scenario has been considered in this interpretation.

Stage 3: From farm to market

The movement of produces along marketing chain, from farm to consumer, provides further possibility for additional natural pathogens die-off but at the same time it can be considered as a recontamination source. WHO guidelines, points out that reduction in pathogens resulted from die-off can reach 0.5 to 2 log unit reduction per day and consider it a reliable barrier. In this assessment only 1 log unit reduction has been considered as a result of this barrier.

Stage 4: From market to consumer

At consumers level a considerable barriers exist and should not be overlooked. While the risk remains exist in case of eating fresh leaf and root crops without washing or/ and peeling, of course for the cooked-eaten types it disappears immediately while cooking. Therefore, consumers themselves can play role in pathogen reduction through implementing certain health-protection measures before eating.
According to the recommendations of the new WHO guidelines the following processes **(Post-treatment barriers)** can bring in significant reduction in biological contamination as follows:

1. Washing: 1 log unit reduction.
2. Washing with disinfectant: 2 log unit reductions.
3. Peeling: 2 log unit reductions.
4. Cooking: 5-6 log unit reductions.

Generally speaking, one can say without hesitation that the hygiene conditions for Jordanian people are relatively high due to good and effective hygiene education. As is the case, realizing 1 to 2 log unit reduction for leaf and root crops as result of washing and peeling is very likely to happen.

At the level of stages 2 and 3, a State Crop Monitoring Programme for fresh vegetables is conducted by JFDA, where samples are taken directly from farms and market as a last step in the monitoring process along the chain of food production. This programme has been initiated since 2004 and is testing samples for chemical and biological parameters. Results of 4 years state crop monitoring program for biological contamination on crops confirmed that risk of biological contamination is confined in leaf crops and root crops (GTZ 2004-2008) as illustrated in table (2). In the view of project team, the reasons of this contamination could be either

- Spreading fresh manure on the soil surface without proper incorporation into the soil
- Or the use of irrigation water in washing leaf and root crops

Annex 1

Assessment of the impact of health-protection (pre- and post-treatment) measures on E. coli levels Upstream and Downstream of KTR

Health-protection measures[1]	Pathogen reduction (Log units)		Scenario 1 (High contamination)			Scenario 2 (Moderate contamination)			Scenario 3 (Low contamination)		
			E. coli Counts			*E. coli* Counts			*E. coli* Counts		
From WWTP to farm gate											
Pre-treatment	**0**		10^8			10^8			10^8		
Post-treatment (WWTP' effluent)	**2-6**		10^5			10^4			10^3		
King Talal Reservoir-inlet[2]	**0**		10^5			10^4			10^3		
King Talal Reservoir - outlet[2]	**1**		10^4			10^3			10^2		
King Abdullah Canal-South[2]	**0**		10^5			10^4			10^3		
On farm											
Water pond	**0**		10^5			10^4			10^3		
Drip Irrigation	**0**	Root crops	**Vegetables**	**Leaf crops**	**Root crops**	**Vegetables**	**Leaf crops**	**Root crops**	**Vegetables**	**Leaf crops**	**Root crops**
	2	Leaf crops	10^1	10^3	10^5	10^0	10^2	10^4	10^{-1}	10^1	10^3
	4	Vegetables									
Pathogen die-off (after last irrigation/ before harvesting)	**1**	Scenario 1	10^0	10^2	10^5	10^{-2}	10^0	10^4	10^{-3}	10^{-2}	10^3
	2	Scenario 2,3									
	0	Root crops									
Washing of produce with RW before marketing	**0**		-	10^5	10^5	-	10^4	10^4	-	10^3	10^3
From farm to market											
Pathogen die-off	**1**		10^{-1}	10^4	10^4	10^{-3}	10^3	10^3	10^{-4}	10^2	10^2
From market to consumer											
Before produce consumption	**0**		10^{-1}	*10^4	*10^4	10^{-3}	*10^3	*10^3	10^{-4}	10^2	*10^2
Produce washing	**1**		10^{-2}	*10^3	*10^3	10^{-4}	10^2	*10^2	10^{-5}	10^1	10^1
Produce Washing + disinfection	**2**		10^{-3}	10^2	*10^2	10^{-5}	10^1	10^1	10^{-6}	10^0	10^0
Produce peeling solely	**2**		10^{-3}	-	*10^2	10^{-5}	-	10^1	10^{-6}	-	10^0
Produce washing + peeling	**3**		10^{-4}	-	10^1	10^{-6}	-	10^0	10^{-7}	-	10^{-1}
Produce disinfection + peeling	**4**		10^{-5}	-	10^0	10^{-7}	-	10^{-1}	10^{-8}	-	10^{-2}
Produce cooking	**6**		0	0	0	0	0	0	0	0	0

Source:

[1] WHO Guidelines for the safe use of wastewater, excreta, and graywater.

[2] Royal Scientific Society (RSS) Annual Reports.

*** Intolerable bio-contamination level (*E.Coli* Counts), risk is high.**

Table interpretation

The table above shows three scenarios of bio-contamination levels (expressed in *E.coli* counts). In scenario 1, the irrigation water quality is the worst with level of *E.coli* 10^5 ($\leq 10^5$ FC/100 ml) .The total reductions in pathogens due to the drip irrigation and die-off together is enough to minimize risk to acceptable and safe level but washing produce with RW, if happened, re-contaminate the crops. In this case, the intolerable level of bio-contamination is expected to remain exist in both leaf and root crops which are eaten uncooked. Hence, it calls for certain health-protection measures from consumers before eating such crops to lower the risk to the acceptable safe level (10^2, 10^1 for leaf and root crops respectively).Failing to realize this reduction pose high disease risk on consumers.

In scenario 2, moderate level of *E.coli* 10^4 ($\leq 10^4$ FC/100 ml) in irrigation water is assumed. The impact of combined barriers (treatment and non treatment) before it reaches the consumers brought down the biological contamination to a level of 10^{-2} for vegetables, and 10^0 for leaf crops and 10^3 for root crops. In case produce is washed with RW, bio-contamination levels rises up again to become 10^4 for leaf and root crops. From there, the required reduction is 2 log unit for leaf crop and 3 log units for root crops. Assuming 1 log unit reduction as a result of die off, then the only 1 log unit is required for leaf crops and 2 log unit reduction for root crops. These reductions should be achieved by consumer through washing leaf crops and peeling root crops.

In scenario 3, as the bio-contamination is low, level of *E.coli* 10^3 ($\leq 10^3$ FC/100 ml), vegetables and leaf crops are expected to arrive consumers with low risks after they pass across the reduction barriers. This scenario show that the contamination risk remains confined to root crops where washing still needed to obtain 1 log unit reduction.

Conclusions:

1. In Jordan, both treatment and post-treatment measures are available which render health risk management approaches an attainable objective.
2. As the crops arrive consumer with unknown levels of contamination (to him), consumer should always assume the worst scenario (high contamination) and act accordingly.
3. To achieve the safe consumption of uncooked leaf crops, consumers should wash it with disinfectants whereas peeling off fresh eaten root crops is demanded besides washing with disinfectant.
4. The existing standard of wastewater effluent is too stringent and can't be met in the light of the results of the existing state-run monitoring programme (JVA and RSS) for the irrigation water quality, therefore updating for JS 893/2006 standard is needed and a realistic irrigation water quality standard should be developed.

Table (2): Summary of Fresh Vegetables Quality Results from 2004 till 2008

Season	Total number of samples	E. coli		Salmonella		Shigella		Pb		Cd		NO_3	
		Tested samples	No. of violated samples	Tested samples	No. of violated samples	Tested samples	No. of violated samples	Tested samples	No. of violated samples	Tested samples	No. of violated samples	Tested samples	No. of violated samples
2004	22	22	0	22	0	___	___	___	___	___	___	___	___
2005	40	40	0	40	2[d]	___	___	___	___	___	___	___	___
2007	151	151	0	151	0	___	___	151	0	151	4	19	14[b]
2008	94	94	3[c]	94	3[a]	78	0	27	8	27	1	20	0

[a](Spinach, Lettuce and Mint)
[b] lettuce Samples
[c]2 leafy crops (Parsley and Spinach). 1 root crop (Carrot)
[d] sweet pepper and lettuce

Reference

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