The Application of Water footprint in Agri-Product Supply Chain Management: Case Study on Corn Seed Production

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Abstract. Water Footprint, as a quantified indicator to evaluate environmental impact, is popular in both direct and indirect water use of a product or service as well as supply chain management optimization. Agriculture sector is the largest water resource consumer and corn seed is not only a kind of agricultural product but also means of agricultural production. Therefore, it is meaningful for assessing water consumption of agriculture sector to calculates the water footprint of corn seed production. In this study, a process-based life cycle assessment (LCA) methodology was used to assess the water footprint of one brand produced corn seed in Gansu Province, China, with both volumetric and stress-weighted results reported. Water footprint values were compared among different life cycle stages and products, and possible mitigation strategies to minimize the burden on freshwater systems from consumptive water use were raised. The results demonstrated the suitability of water footprint as streamlined indicator in product supply chain management for the selected products and affirmed the importance of farming stage for water footprint reduction. Foot printing values were compared among different life cycle stages and possible mitigation strategies were put forward for water use reductions throughout the supply chain.

Introduction

Freshwater is the most essential of natural resources, yet freshwater systems are directly threatened by human activities[1] and agriculture is the largest freshwater consumer, accounting for more than 70% of the world’s water withdrawals. Water footprint is being used to indicate the water use and impacts of production systems on water resources. Water footprints have been reported for a wide range of products to evaluate the impacts of production on water resources and highlight opportunities of sustainable production.

Corn seed production is a critical sector for agriculture and places a significant demand on water resources. Hexi corridor, located in Western Gansu Province, is the largest corn seed production base of China, accounting for 70% of the national corn seed production, due to its favorable natural and geographical conditions. Ministry of agriculture of China and Gansu provincial government have built 20,700ha national corn seed production base here. Meanwhile this region, with a temperate continental climate, was separated from ocean warm air by Qinghai-Tibet Plateau, Mongolia Plateau and Loess Plateau, which leads to a dry climatic condition and fewer opportunities of raining. Annual precipitation ranges from 50 to 300mm and annual total evaporation ranges from 2000 to 3000mm. Therefore, the rationale behind studying water footprints for corn seed production systems is the fact that water is an essential input to the entire production process, especially for the farming phase which highly depends on irrigation.

Life cycle thinking, applied through life cycle assessment(LCA) is increasingly recognized to address issues of environmental impacts and sustainability. Although a complete LCA includes all relevant impacts, water footprint is becoming a standalone indicator and growing in importance[2]. LCA-based water footprinting is aligned with a key global environmental issue of freshwater depletion and become a mainstream indicator in the discussion of sustainability. Previous studies on dairy and soybean products[3, 4] in China have reported water use at the midpoint level based on LCA. As a result, it is meaningful and feasible to employ LCA-based footprinting to study the water footprint of corn seed production in Hexi corridor and sustain its production.

The objective of this study is to assess the impacts of the corn seed supply chain on local water resources. For this, we used LCA-based method of water footprinting and conducted a detailed inventory of life cycle water consumption of corn seed production in Northwest China. The water footprints of corn seed were subsequently compared between two different factories, of which one produced corn seeds by ordinary technics and the other had new-type manufacture line.

Methods and materials

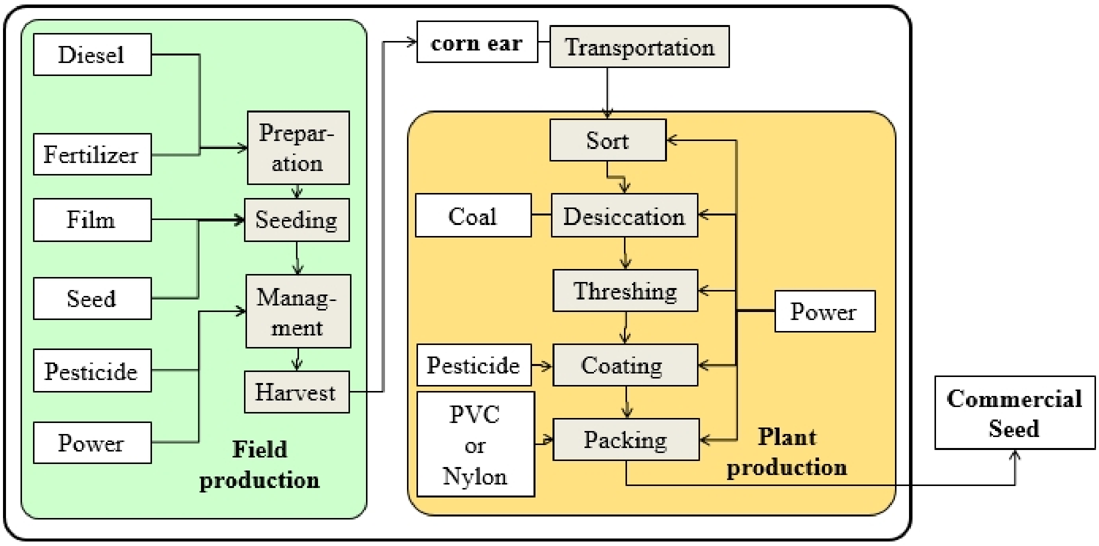
Water footprint calculation was based on Life cycle analysis(LCA), which was consistent with PAS2050:2008. The modeling procedure included goal and scope definition, inventory analysis, impact assessment and result interpretation, which are standardized by ISO for an LCA study.

Goal and scope definition

The goal of this research was to apply LCA-based water footprint modeling method to corn seed production from two different factories, of which production lines employ different desiccation and packing technics, quantify the total consumptive water of corn seed production and compare the environmental impact of two different supply chains. The functional unit of finished corn seeds was defined as 1t, which were 1t corn seeds produced by ordinary beltline (CSO) and 1t corn seeds derived from a new type of beltline. Two factories are both located at Jiuquan City in Gansu province in northwestern China. Primary data was collected from factory operators, experts and farmers living on corn planting.

The supply chain of corn seed production could be divided into farming, transportation, manufacture and packing which was defined as “cradle-to-gate”. Consumption and utilization phases of corn seeds were not considered in the system boundary, since they were complicated to assume but responsible for much less water use compared with other stages. Desiccation was a basic and critical procedure of corn seed manufacture meanwhile the two factories investigated apply ordinary and new boilers respectively therefore, desiccation was taken into account singly, separated from manufacture. In result, the phases across the corn seed production were further and finally defined as farming, transportation, desiccation and manufacture.

Fig 1 System boundary for life cycle of corn seed production



Inventory analysis

The inventory throughout the supply chain related to water footprint modeling was constructed covering the financial year 2012. Construction of infrastructure, farmland and plant was not included in the system boundary with reference to PAS2050. At the stage of corn farming in Jiuquan City, input data, including the typical amounts of fertilizers, pesticides, electricity, fuel use, and water use, was considered to be of high quality since they were provided directly by the farmers in face to face conversation. For the transportation procedure, corn seeds were transported from farmland to the factories using two types of trucks including 2-ton light trucks and 18-ton heavy trucks, which were obtained by communicating with managers of factory logistics. For desiccation and manufacture phases, information about specific technics and their input data covering process water use, electricity and material consumption was collected on the basis of corporation's production records and communication with plant experts.

Water use was differentiated as green water, blue water and grey water. The consumption of green water is considered as the rainfall that can be intercepted effectively in crops. Two components of blue water were considered: irrigation water at the farm; water consumed in the production of farm and factory inputs which include the utilization of manufacture and transportation. Grey water refers to the volume of water needed to assimilate the pollutants in water body. Green water consumption for corn cropping was simulated by SIMETAW since the simulated ACEr was lower than the ACETc. Blue water related with transportation and input materials such as electricity, fertilizer and wrapper was adapted from Chinese Core Life Cycle Database 7.0 and Ecoinvent2.0.

Impact assessment

Impact assessment was used to assess the environmental relevance of consumption water flows in relation to freshwater scarcity. The water stress index (WSI) developed by Pfister et al [5] was chosen as the local water stress characterization factor for freshwater consumption. The WSI values used in this study were profiled in Table 1 and the national average WSI for China (0.478) was used in relation to farm and industrial inputs where the location of production was uncertain. In the case of water footprint calculation, the respective volumes of blue water at the place of consumption were multiplied by the relevant water stress characterization factors and then summed across the system. The product water footprint is then normalized by using the China's average water stress index (0.478) to give China's equivalent water footprints in Liter.

Table 1 WSI values for locations related to the value chains

Location	Gansu province	Shandong province	Hami city	Xinjiang province	Zhejiang province	China
WSI	1	0.999	1	1	0.641	0.478

Result interpretation

Water footprint values of corn seed production were compared between different factories and different life cycles stages. Based on the water footprint results, relevant optimization strategies were proposed to detect the potential of water use reduction across the production procedure and assist product supply chain management.

Result

Water use inventory

The volumetric water use for each functional unit within different life cycle stages was profiled in Table 2. Green water consumptions and grey water requirements were much smaller than the blue water demanded for both 1t CSN and CSO. The heavy reliance on irrigation water in farming production systems led to much higher blue water against green water. Grey water was large enough to come into notice since nitrogen losses were serious in corn farming phase. Farming took up the absolute majority of blue water use while transportation, desiccation and manufacture contribute much less to blue water use.

Table 2 Water use inventory

	1t corn seeds-ordinary	1t corn seeds-new
green water (L)	144.43	144.43
grey water (L)	61.34	61.34
blue water (L)	1012.88	1012.79
farming	1012.18	1012.18
transportation	0.04	0.04
desiccation	0.11	0.07
manufacture	0.56	0.50

Stress-weighted water footprints

For the corn seeds from two factories, 1t CSO and 1t CSN, total water footprints from cradle to gate were 1218.65 and 1218.56 L H_2Oe per functional unit respectively. The farming stage dominated the total water footprint during the entire supply chain. For 1t CSO, farming accounted for 99.94% followed by manufacture. Less than 0.02% of the product life cycle water footprint generated during transportation and desiccation. For 1t CSN, the proportions of each stages were same.

The distribution of water footprint across supply chain showed a prominent feature that absolute dominance of farming phase was observed. In the corn seed product case, the irrigation water inputted into corn cropland was the largest contributor as reflected by the high blue water footprint values. Some fertilizers consumed during farming phase, all of coal burned during desiccation phase and packing materials used during manufacture phase were sourced from other provinces, which resulted in water use during transportation process.

Opportunities to reduce product water footprint

Farming was the largest contributor for water use and water footprint. The corn farming systems in Hexi corridor highly relied on a large number of irrigation. Consequently, it is important to up our efforts to improve irrigation water use efficiency, decrease runoff and increase the productivity of rain-fed corn production systems. In order to achieve these targets, factories can make water-saving agreements with their corn farmers, additionally, government should also encourage farmers to adopt more water-saving farming practices by some incentives such as water-saving allowance. Otherwise, reducing nitrogen and phosphorus losses from farmland will decrease the amount of grey water and bring down the total environmental impact of farming stage.

In spite of the minor water use ratio of transportation, desiccation and manufacture, the environmental impacts from these stages could be effectively decreased by optimizing ingredient sourcing plans and adjusting new-type equipment and techniques.

Discussion

In farming stage, corns, used to produce seeds, were cultivated in two areas of which croplands were supported by traditional surface water irrigation (30%) and groundwater irrigation. Surface water irrigation was implemented by utilizing gravity without consumption of electricity while groundwater irrigation implemented by electricity to overcome gravity. However, surface water irrigation areas generate larger water footprint to produce 1t corn seed due to its higher water consumption and lower corn yield than groundwater irrigation areas. Additionally, compared with traditional surface water irrigation, groundwater irrigation offers more reliable supplies, lesser vulnerability to droughts, ready accessibility for users and higher corn yield. Hence, drip irrigation infrastructure could be established to adapt the sandy loam, with poor water capacity and large water consumption by flood irrigation, in surface water irrigation areas. Meanwhile more efforts should be upped to increase the irrigation water use efficiency for both surface water irrigation areas and ground water irrigations areas.

After being transported in the two factories, the fresh corn ears would be desiccated by boilers of different types during desiccation phase. One type of boilers can only use coal as fuel, another type of boilers can also use corn cobs as fuel besides coal, which can reduce the consumption of coal resources and decrease the stress-weighted water footprint across desiccation stage by 31.82% compared to the traditional only fuel-burned boilers. Thus, the mixed fuel-burned boilers, utilizing both coal and corn cobs as fuel, should be promoted to more corn seed manufacture factories with the aim of not only water footprint reduction but also coal resources conservation.

For manufacture stage, the stress-weighted water footprints of 1t CSN and 1t CSO were similar while the water footprints before multiplied by WSI of two products were different. Therefore, two tips on reducing environmental impacts can be considered. Firstly, more polyvinyl chloride of packing materials could be replaced by nylon because producing nylon consumes less water. Secondly, the nylon could be transported from other provinces where water resources are abundant and WSI is lower.

The stress-weighted water footprints depict the environmental impacts from water consumption and reflect the local water scarcity where progresses occur. Stress-weighted water footprint should be applied as a sustainability indicator to assist product sustainability at the basis of inventory water use profiled together.

Frequent tradeoffs would be assessed among water use, greenhouse gas emissions and other relative environmental impact indicators in a more comprehensive life cycle impact assessment. Similarly, strategies to cut down water footprint may might increase GHG emissions. Thus, more indicators should be taken into account during environmental impacts study like product footprint study, especially GHG emission which have aroused much attention recently due to its significant impacts on climate changes.

Conclusion

This paper applied water footprint as a sustainability indicator to assess the environmental performance of corn seed production. Water footprint was applied as an indicator to evaluate the environmental impact of two corn seed products from different factories. Water footprint values were reported and optimization strategies were put forward to cut down water use and environmental impact across product life cycles. Farming stage was the most important point for water saving and its environmental impacts occurred far beyond where the consumption and plant manufacturing took place. In addition, water footprint is a single indicator that only focuses on water resources consumption hence additional environmental impact categories such as carbon footprint as well as social and economic concerns should be taken into account to make final optimization strategies.

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