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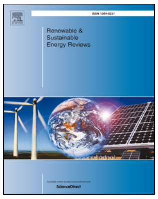

Environmental sustainability of corn (*Zea mays* L.) production on the basis of nitrogen fertilizer application: The case of Lahijan, Iran

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ABSTRACT

A field experiment was conducted in Lahijan, Iran to determine the environmental impact of four corn (*Zea mays* L.) genotypes production under three nitrogen (N) fertilizer application rates using the life cycle assessment (LCA) methodology. Treatments consisted of three N levels (300, 400, and 500 kg ha^{-1} of urea) and four corn genotypes (KSC 647, KSC 700, KSC 704, and a local variety). Six impact categories, i.e., global warming, acidification, terrestrial eutrophication, depletion of fossil resources, depletion of potassium resources and depletion of phosphate resources, were determined. There was an increasing trend in grain yield with increasing N rate from 300 to 400 kg ha^{-1}, but further increase in N rate (500 kg ha^{-1}) was not beneficial for all genotypes. The highest grain yield (14.49 t ha^{-1}) was observed for the hybrid KSC 647. The maximum values of environmental index (1.53) and resources depletion index (1.11) were determined in the production of one tonne of grain yield for the local corn variety treated with 500 kg ha^{-1} of urea. The production of one tonne of grain yield by the hybrid KSC 647 treated with 300 kg ha^{-1} of urea emitted the least amounts of NH_3, N_2O, NO_X, CO_2, CH_4, and SO_2 (2.158, 0.368, 0.449, 64.510, 0.090, and 0.115 kg per tonne of grain yield of corn, respectively). The selection of superior genotypes in terms of grain yield and low N consumption showed lower damage to the environment. The use of high-yielding genotypes increases productivity and alleviates the environmental impact of production.

1. Introduction

Sufficient food of high quality with minimum impact to the environment remains a major challenge for agricultural production in the 21st century [1]. Appropriate fertilizer use in crop production is essential for sustainable agriculture with limited environmental impact [2]. Many grain legumes, such as soybean and beans, have nitrogen (N) fixing bacteria, requiring limited doses of N fertilizers [3]. However, certain cash crops, such as maize, are big consumers of N and consequently of energy, with differences among genotypes [4]. In this respect, breeding is of crucial importance in developing genotypes with maximum productivity and minimum environmental impact. Thus, breeders play an important role in developing cultivars that are resistant to pests and diseases and have appropriate morphological characteristics for easy cultivation and harvest, in addition to their high productivity and tolerance to environmental stresses [5]. Some researchers suggest that advanced cultivars, which exhibit optimum growth and yield under nutrient-rich conditions and treated with herbicides and receive irrigation, are not capable of producing good yields under input-limited conditions and environmental stresses [6–9]. Others believe that cultivars with high yielding ability under nutrient-rich conditions can cope also with environmental stresses, a fact that assists in the selection of genotypes with the least environmental impacts [10,11]. Thus, one breeding method is the introduction of cultivars that can be used for selecting superior genotypes with the least environmental impacts [12,13]. Extensive use of chemical fertilizers, especially N fertilizers, is one of the most important environmental problems in the world and serves as a main source of ammonia emission to the environment [14]. The agricultural sector in Iran is a major energy consuming sector, emitting about 40% of N_2O, whereas the share of this sector in the emission of CO_2 and CH_4 is about 2% [15].

One of the methods to evaluate the environmental impact of a product is the life cycle assessment (LCA) methodology, which assesses the whole life cycle of a crop production process from raw material

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extraction or from gathering to consumption and then recovery or disposal of wastes. The method quantifies all resources used in production and all emissions to the environment [16]. LCA is a method that assesses the capacity of environmental impacts of a production or a specific process by defining two components: the use of resources and the emission of pollutants to the environment [17]. Increasing agricultural production depends on extensive application of agricultural inputs, including fertilizers, pesticides, and use of machinery, which creates severe environmental problems like eutrophication [18,19]. The consumption of farming materials and the pathways and magnitudes of N losses differ considerably under different crop management regimes. For a comprehensive and reliable assessment of the overall greenhouse impacts of different farming practices, a holistic analysis, including all related fluxes, would provide more meaningful information for the identification of mitigation strategies leading to the lowest footprint, while maintaining crop yield. Managing N through fertilizer application is of major importance in mitigating emissions and one of the most effective management practices to sustain crop yield [20]. Thus, to reduce emissions, future efforts should be directed to developing techniques that enhance N use efficiency, reduce reliance on synthetic fertilizers, and optimize N fertilizer application rate without negatively affecting crop productivity and soil fertility.

A lot of environmental pollutants are produced by modern agriculture [21,22]. Extensive studies have been oriented towards the environmental assessment of crop production in recent years [21,23–26]. In Gorgan, Iran, an LCA to estimate environmental impacts of wheat production showed that crop production in that region entailed considerable environmental impacts in terms of depletion of non-renewable energy resources, eutrophication, photochemical oxidation, and acidification [14]. Another study on wheat in Marvdasht, Iran, showed that among environmental impacts, terrestrial eutrophication had the highest potential to damage the environment [27]. A study on the energy budget of barley production reported that its energy efficiency was less related to the high rate of fertilizer and machinery use [28]. Khan et al. [29] estimated the share of chemical fertilizer to be 43% and 47% of the total energy input in rice and wheat production systems, respectively. Application of synthetic N fertilizers (such as urea) results in nitrous oxide (N_2O) emissions, with corn production being a major source of greenhouse emissions from the production process [30]. Despite the growing rate of LCA use for agricultural activities due to the increasing importance of their environmental problems in recent years, the results published for grains in Iran, especially for corn, is not yet adequate. On the other hand, the role of different (bred and local) genotypes has not been evaluated through LCA. The objective of the present study was to compare different corn genotypes production on the basis of N fertilization rate and determine the optimum N rate with the least environmental impacts for corn cultivation in Guilan Province, Iran through the LCA methodology.

2. Materials and methods

2.1. Crop establishment and experimental design

The study was carried out in a field in Lahijan area (lat. 37°12' N, long. 50°01' E, altitude 34.2 m) of Guilan Province, northern Iran in April 2015. The soil type was clay loam with 39% clay, 32% silt, and 29% sand, pH (1:1 H_2O) 7.1, organic matter 2.78%, and electrical conductivity (EC) 1.54 mmhos/cm. The field was in fallow in the previous growing season. The seedbed was prepared according to standard tillage practices, including disc and rotary cultivator after semi-deep plow.

The experiment was established in a randomized complete block design (RCBD) with a split-plot arrangement and three replications. The treatments included three rates of N fertilization (300, 400, and 500 kg ha^{-1} of urea) as the main plots and four corn genotypes (KSC 647, KSC 700, KSC 704, and a local variety) as the sub-plots. KSC 647 requires 126.5 days to physiological maturity and provides grain yield 15.8 t per ha, KSC 700 requires 128.3 days to physiological maturity and provides grain yield 18.4 t per ha, KSC 704 requires 127.2 days to physiological maturity and provides grain yield 17.1 t per ha, and the local variety requires 100–120 days to physiological maturity and provides grain yield 4–6 t per ha. Due to heavy irrigation and to avoid the disruption of N fertilization treatments, a split-plot design was used in which N fertilization was laid upon randomized complete blocks. First, the farm was divided into three blocks and the blocks were divided into three main plots, which represented the three N rates. Next, the main plots were sub-divided into four sub-plots, where corn genotypes were randomly assigned. Each sub-plot consisted of four corn rows 3-m-long with an inter-row spacing of 75 cm and an inter-plant spacing of about 25 cm on the row. The experimental field was composed of 36 sub-plots, each spaced 50 cm apart. The number of sowing rows was 4, 16 and 48 in each sub-plot, main plot, and block, respectively.

According to the recommendation of the Seed and Plant Improvement Institute and of the soil analysis, 400 kg ha^{-1} of urea (containing 46% net N, 184 kg ha^{-1} N), 300 kg ha^{-1} of triple superphosphate (containing 46% P_2O_5, 60 kg ha^{-1} P), and 50 kg ha^{-1} of potassium sulfate (containing 50% K_2O, 21 kg ha^{-1} K) were applied. To compare the environmental impact on the basis of N fertilization in terms of corn yield, N rates of lower and higher than those recommended (i.e., 300 and 500 kg ha^{-1} of urea or 138 and 230 kg ha^{-1} N, respectively) were applied. All phosphate and potassium fertilizers and half of the urea fertilizer were applied as a basal treatment before sowing and the remaining half of the urea fertilizer was applied to the soil surface at the five- to seven-leaf growth stage of corn. The studied genotypes were three hybrids (KSC 647, KSC 700, and KSC 704) procured from the Seed Department of the Seed and Plant Improvement Institute as well as a local variety of Astaneh-ye Ashrafiyeh, as described above. During cultivation, young plants were earthened up at the two-leaf stage. Weeding was carried out manually and mechanically at the five- to seven-leaf growth stage of corn. Corn was irrigated regularly during the growing season with a furrow irrigation system. In this method, the water flows down the furrows (often using only gravity) and it seeps vertically and horizontally to refill the soil reservoir. Furrow irrigation is suitable for many row crops. Irrigation consisted of six water applications throughout the crop season at a dose of 90 mm. Severe pest or disease problems did not occur in the growing season. Therefore, no prophylactic or need-based applications of pesticides were performed. The plots were harvested on August 17, 2015. The plants of the two central rows of each plot were sampled and plant height was determined in five randomly selected plants of each row. To determine grain yield and yield components, the samples were oven-dried at 70 °C until constant weight and then ear length, grain length and width, 1000-seeds weight, and grain yield were determined. Dry weights were measured by a 0.01-precision digital balance. Grain yield was adjusted to 13% moisture and expressed as tonnes per ha. Basic weather data during the experiment are given in Table 1.

Table 1
Basic weather data during the experiment.

Month	Mean temperature (°C)		Total rainfall (mm)		Sunshine hours per day	
	Growing season	10-yrs average	Growing season	10-yrs average	Growing season	10-yrs average
April	15.5	16.1	0.0	2.9	9.2	4.4
May	19.9	21.4	0.9	1.4	6.4	5.9
June	24.7	25.8	0.1	2.3	9.9	7.3
July	26.4	27.9	3.7	2.2	8.7	7.3
August	27.4	28.7	0.0	2.4	8.9	7.2