Estimation of Maize Yield Per Harvest Area

Subjects: Agriculture, Dairy & Animal Science

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Maize (Zea mays L.) is one of the most important annual cereal crops in the world, providing a staple food, and being used as source of income for many populations in developing countries. Different methods can be used for estimating maize yields depending on the purpose for which the crop was produced. The estimation of yield can be calculated using kernel weight at harvest, plot area harvested, plant density, and moisture content of grain at harvest.

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1. Introduction

Maize (*Zea mays* L.) is one of the most important annual cereal crops in the world, providing a staple food, and being used as source of income for many populations in developing countries. The way maize is processed and consumed greatly varies from country to country, with maize flour and meal being the most popular products [1][2]. It is an important source of carbohydrate for human diets in developing countries and for animal feed in the developed world [3].

Evans and Fisher [4] defined yield as being the mass of product at final harvest, with specified dry matter content. Crop yield is broadly defined as the amount of harvest product in a specific area (amount of harvest products/crop area) [5]. The grain yield of maize depends on the genetic potential of the genotype used, the characteristics of the soil, the field management practices, and agro-climatic factors [6][7]. Potential yield refers to the maximum yield that can be attained by a crop in a given environment [4]. Potential yield is largely determined by a specific combination of factors, such as solar radiation, soil type, temperature, plant density, genetic potential of a given genotype, biotic and abiotic constraints [8][9][10]. However, realized yield, also known as attainable yield, obtained by a farmer is more frequently influenced by poor agricultural practices [9]. Maize yields can be estimated for different purposes, including marketing, estimation of storage requirements, organizing harvest equipment, making decisions about pests and diseases, and for crop improvement. Maize yield estimates are also used to forecast production, and thus contribute to the estimation of food security status at district, provincial, and national levels.

Different methods can be used for estimating maize yields depending on the purpose for which the crop was produced. The estimation of yield can be calculated using kernel weight at harvest, plot area harvested, plant density, and moisture content of grain at harvest. For instance, to get the full expression of maize yield potential, the plants must be at optimum density. In some circumstances, the maize planted area may be bigger than the plot area harvested because of poor germination, pest and disease damage, animal grazing, floods, lack of labor for harvesting, and lack of adequate markets for the product [11]. The methods used to estimate crop yields are crop cuts (on-station, on-farm trials), statistical techniques, farmer estimates, whole plot harvest methods, the sampling of harvest units, expert assessments, and yield prediction through simulation models (such as crop modelling and remote sensing) [11].

2. Components of Maize Yield Estimates

In each agro-climatic environment, yields of maize plants are influenced by several components linked to agronomic practices that are used. These are plant population density (determines number of cobs and kernels harvested in a given area), the shelling percentage, and the amount of water in the harvested grains. The magnitude of yield components is a function of the physiological response of a crop to the growth environment, which is of great importance to maize physiologists, modelers, and breeders.

2.1. Plant Density and Kernel Number

Plant density refers to the total number of plants grown in a given area, and it is an important factor in yield estimation. Maize density is calculated based on row spacing, row length, number of plants per planting station, and the distance between two consecutive planting stations. Ali et al. [12] estimated maize plant density per plot at physiological maturity by counting the total plants in the plot and dividing by soil area. Maize density has been widely investigated worldwide. An increase in plant density results in relatively higher yield increments if the appropriate fertilization rates and agronomic practices are adopted [13]. Huang et al. [14] found a 5% yield increase of diamond plants at high density (90,000 plants ha^{-1}) resulted in increased kernel numbers per ear in the top and middle canopy layers. Moreover, they reported that the optimum distribution of light in the canopy delayed leaf senescence, especially for plants with a triangle shape. In a dense population, canopy architecture becomes an important factor determining yield because of interplant competition for light distribution and absorption [15].

Maize grain yield is normally highly and positively correlated with kernel numbers. The number of kernels per plant depends on the number of ears per plant and the number of mature kernels per ear [16]. To produce more grain per unit area, the genetic potential of most recent hybrids takes advantage of their capacity to withstand higher densities [17]. Qian et al. [18] reported that spring maize hybrids attained an average increase of 17.9 g per plant per decade, which corresponds to an increase of 936 kg/ha per decade over the period from 1970 to 2010 in Northeast China. The yield gain was attributed to an increase of yield per plant, resulting from an increase in number of kernels per ear and an increased 1000 kernel weight under appropriate agronomic practices.

Several spacings have been recommended, given a required number of plants per unit area in various regions in the world, as indicated in the map (**Table 1**). The various distances between rows and hills in a row have been estimated for a resultant density of 53,000 plants per hectare. Plant spacing impacts the number of individual plants grown on a given area and will therefore influence the number of ears harvested and the resultant yield. Plant spacing is usually based on the agro-climatic conditions, the plant material used, and the cropping system (monoculture or mixed culture). Therefore, spacing varied from region to region and sometimes from one country to another. Large distances between rows facilitate use of mixed cropping systems. The number of plants can be increased by either reducing the spacing between hills in a row or reducing the distance between rows. When the distance between two consecutive hills is very small, the number of plants per hill tends to be one.

Table 1. Some plant densities and spacings used in various agro-ecological environments for maize production.

Country	Environment	Plant Density/ha	Spacing between Rows (cm)	Spacing within the Row (cm)	Average Mean Yield per Region (t/ha)	References
Hungary	Humid forest zone	67,486 to 70,161	70	20	8.5	[19]
Kenya	Tropical climate and bimodal rainfall Nairobi	44,444 53,333	75 75	60 25	2.0	[20] [21]
Serbia	Calcareous chernozem on loess terrace	60,606	75	22	4.9	[22]
Rwanda	Congo–Nile Crest region	55,000	60	30	4.0	[23]
Pakistan	Faisalabad	66,500	75	20	2.9	[24][25]
India	Coimbatore	66,667	60	25	2.7	[26]
Cameroon	Low and high land areas	53,333	75	50	1.8	[27][28][29][30][31]
Nigeria	Northern Guinea Savana agro-ecological zone	53,333	75	25	5.5	[32]
Brazil	Frederico Westphalen	70,000	70	20	5.6	[33]

An increase in maize density significantly increased plant height, ear height, and yield. However, some yield parameters such as ear length, number of grains per row, number of grains per ear, grain weight per ear, cob weight, and 1000 grain weight were decreased by increase in maize density [35]. This is because of the competition among plants for nutrients uptake from the soil and for light absorbance as well. Some individuals would tend to grow taller and some failed to bear ears, resulting in significant decreases in overall yield. Short maize varieties could be grown at higher plant populations than the taller varieties, which may be susceptible to lodging under high population density. The environmental conditions and genetic potential of some maize genotypes allow them to tolerate high plant density. Mandić et al. [35] reported that a crop density of 71,429 plants ha^{-1} was optimal for

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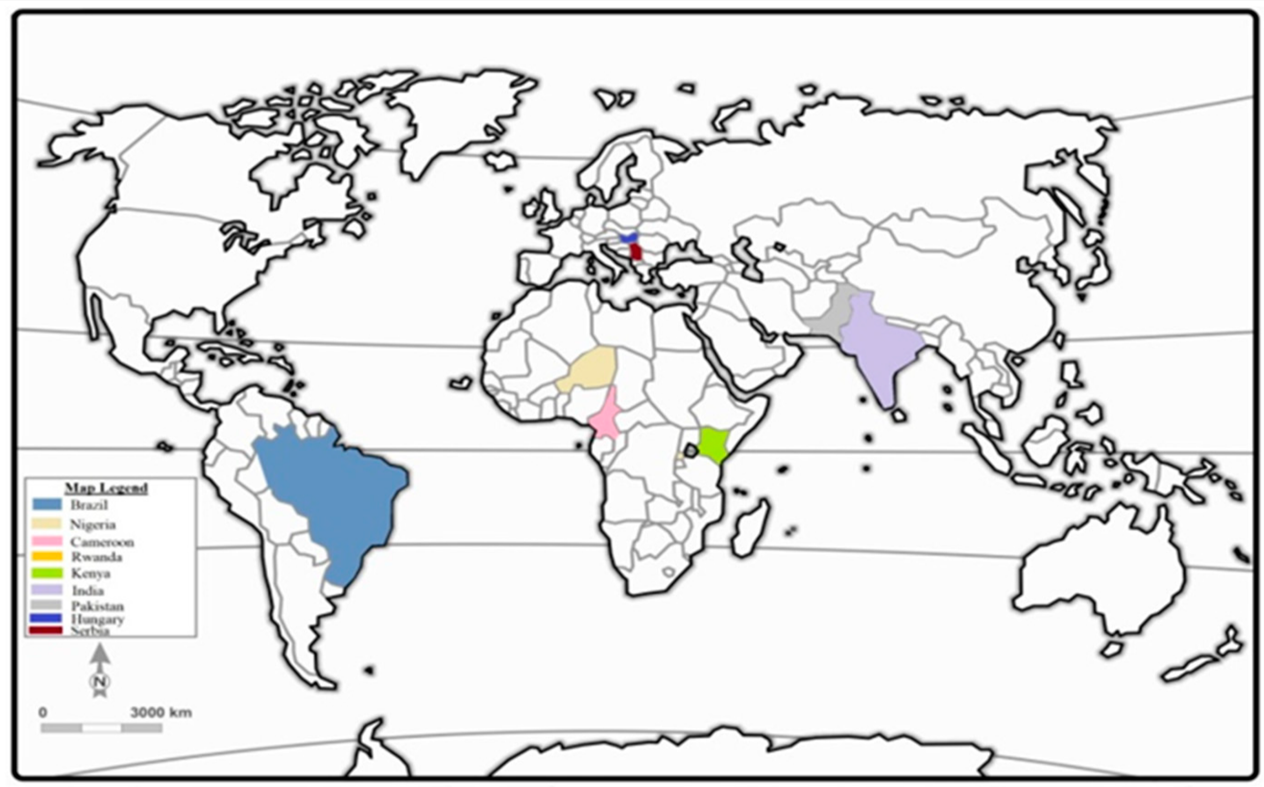

Map modified from [34]: World view of the countries listed above.

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The moisture content can either be determined using a moisture meter or it can be calculated. To estimate the moisture content of grain in a given plot, ten ears should be sampled randomly. Then, the shelled grains from two central kernel rows should be mixed to determine the moisture percentage using portable moisture testers [38]. Estimation of grain moisture content is important because kernel density decreases as moisture content of the grain increases [39]. Bello et al. [28] calculated the moisture content by selecting three hundred grain samples from each of their plots at harvest, weighed and recorded the initial weight. They dried the grains to a constant weight in the oven at 80 °C for 48 h in the laboratory and collected the final weight. The difference between the two weights was recorded as grain moisture content at harvest.

Moisture content also affects grain properties and ease of storage. When the weight of the grain is stable, the grains can be kept for many years. The moisture content of the maize cob can change when dried to less than 15% in storage into an inadequate atmospheric condition [40]. Heisey et al. [41] reported that ear moisture was negatively correlated with grain yield and they suggested that harvesting before physiological maturity of the plant limits grain yield. The moisture content should be standardized to appropriate moisture percentage (ranges from 10 to 15%) when computing grain yield.

2.3. Maize Harvest and Shelling Percentage

Maize harvest is recommended to be delayed until a relatively low grain moisture content has been attained (15–25%) to facilitate shelling and increase the accuracy of moisture meters during data collection [37]. However, a long delay in maize harvesting may cause quantitative and qualitative losses to the grain yield, due to physiological and morphological factors such as development of ear rots, plant lodging, or animal attacks [42][43]. High grain yield and good seed quality are obtained when the harvest is carried out after physiological maturity of the plants [43][44][45][46]. Gaile [47] reported the dry moisture content of maize (min 25%, optimum 28–30%) as the main criterion for determination of proper harvesting time.

The ear weight (in kilograms) of a particular genotype should be recorded after harvesting a plot. Maize shelling is known as the removal of kernels from the cob. The shelling percentage is one of the yield quality measurements that should be estimated. Masuka et al. [48] hand-harvested all the evaluated plants, then measured shelled grain weight and estimated grain yield using 80% shelling percentage. Maize having moisture content of 12% is likely to express the best shelling performance as it will be very easy to remove grains from the cob without damaging them. Horrocks and Zuber [49] reported that different row spacings (50.8, 76.2, and 101.6 cm) resulted in a slight increase in shelling percentage varying from 82.2, 82.6, and 82.8%, respectively. The average shelling percentage of maize ears is usually about 80% when plants are harvested with 20 to 25% moisture content, though this may depend on the agro-ecological zone. The shelling percentage can be determined from ten plants randomly sampled after harvest using the following formula [3][50]:

$$\text{Shelling percentage} = (\text{seed weight}/\text{cob weight}) \times 100\% \quad (1)$$

The shelling percentage is strongly influenced by several factors, such as the method of its determination, years, locations, genotypes, agro-climatic conditions, cultural practices, and kernel moisture content [49].

2.4. Harvest Area

The use of global positioning system (GPS) technology provides an affordable and more reliable alternative method for measurement of plot area harvested in large scale production. Ngie and Ahmed [51] used combine harvesters that recorded the grain weight per hectare within 20 m × 20 m ranges (in kg/ha), associated with a GPS system which recorded the coordinates of the plots against the dry weight of the harvested grain. However, the easiest way of estimating the harvest area for small plots of land consists of multiplying row length by the space between two consecutive rows, and factoring in the number of rows in the plot using the following formula:

$$\text{Harvest area} = \text{row length} \times \text{intra} - \text{row distance} \times \text{number of rows} \quad (2)$$

where harvest area is in m^2, row length is in m, and intra–row distance is in m.

3. Grains yield estimates

Crop yield represents a culmination of the efficiency of the plant population to use available environmental resources for its growth [52]. Crop productivity per unit area is one of the essential indicators for agricultural development. The estimation of crop yield involves estimation of crop area and quantity of harvested products [11].

3.1 Yield estimation from experimental plots

According to Cassman [53], yield potential (Yp) is defined as the biophysical yield obtained with adequate water to avoid deficits, appropriate temperature regime determining the length of the growing season, and the optimum amount of solar radiation during the growing season. However, potential yield (Yw) is obtained from non-irrigated crops or rain-fed crops, which are exposed to water-limited conditions depending on the quantity, the timing of rainfall, and the capacity of soil to store water. The potential yield is obtained from the well-managed crop in a given set of conditions. The determination of grain yield (GY) based on grain weight can be adjusted to a required percentage of moisture content (varies from 10 to 15%) using the following formula [38]:

GY (t/ha) = [Grain weight x 10 x (100 - MC) / ((100 - Adjusted MC) / (Plot area))] (3)

Where GY is in kg, moisture content (MC) is in percentage and plot area is in meter square.

If GY is to be calculated using the ear fresh weight and the adjusted MC percentage (between 10 to 15%), the following formula is recommended:

GY (t/ha) = [(Fresh ear weight (kg/plot) x 10 x (100-MC) x 0.8) / ((100 - adjusted MC) x Plot area)] (4) where 0.8 is the shelling coefficient.

3.2 Yield estimation from Farmers' fields

The harvest yield from farmers' fields is known as actual or realized yield. Most often, in smallholder farms, maize planting does not follow any rule making the estimation of plant density difficult as well as the estimation of the harvest yield. The estimation of crop yield can be complicated by heterogeneous performance of a given crop within a plot, continuous planting and use of mixed cropping systems.

The estimation of crop yield using test weight technique is one of the easiest and quickest pre-estimation methods under farm conditions. This method is based on the sampling frame and can be applied in any farm. The number of ears per planting station is counted in one meter square area, repeated at least 5 to 7 times within the entire plot, where yield is to be determined and the average number is taken. Similarly, the number of kernel rows per ear is counted in 20 to 25 ears randomly selected and the average is used. 1000 kernels are sampled randomly from the ear and weighed. The yield of the crop is then calculated using the following formula modified from Sapkota et al. [54]:

Yield (kg/ha) = [(number of kernel rows per ear x number of ears per meter square /100) x (weight of 1000 kernels (g) / 1000) x 10,000] (5)

The result obtained from the above formula can be multiplied by 1000 to express the yield in t/ha.

3.3 Complex models used in yield estimation

Crop simulation methods can be used to estimate crop growth, yield and improve agricultural management systems by allowing farmers to be prepared for climatic conditions of the forthcoming season [9][55][56][57][58]. Crop modelling and remote sensing are two methods that enable government agencies, private industry and researchers to estimate yield before harvest. Numerous studies have been conducted to predict crop yield at regional scale using remote sensing approaches, yield modelling and a combination of the two methods. There are numerous crop simulation models that take into account the interactions of a crop with climatic conditions, soil properties, and agronomic management practices.

4. Yield simulation

Crop simulation models are mathematical representations of complex real-world systems [59], which can mimic crop growth and estimate crop yield on the basis of weather (precipitation, temperature and solar radiation), soil, and crop management conditions [60][61]. Field crop yield production is important for relevant design of grain storage facilities, agricultural field management, as well as national agricultural decision-making. However, complex models are not always appropriate and do not provide reliable information in all situations because they may require inputs that cannot practically be obtained in field situations [62]. Table 2 summarizes some models that were previously used at various stages of maize production.

Table 2. Some simulation models applied in maize production.

Simulation Model	Objective	Reference
Multi-model forecast and single model forecast: CORN-CROPS model Conformal Cubic Atmospheric model (CCAM) and ECHAM 4.5 model CERES-Maize model Hybrid Maize crop simulation model World Food Studies (WOFOST) model	Early warning during preparation for the new season Simulate the interaction of management practices and weather in determining maize yields Yield estimation Potential yield estimates of maize Simulate the growing process of spring maize	[63] [64] [65] [66] [67]

5. Remote sensing

Remote sensing is a technique to observe the earth's surface, the atmosphere from space using satellites (space borne), or from the air using aircrafts (airborne). In other words, it refers to the activities of recording/observing/ perceiving (sensing) objects or events from faraway (remote) places [68]. Remote sensing is a dynamic monitoring yield estimation technique used in diverse types of crops which can estimate crop yields on a large scale and provide relevant results. It is an important tool for generating agricultural statistics because of the synoptic view and online information provided in a short period of time which can be used to predict yield before harvesting [11][51].

Remote sensing can be integrated with geographic information system (GIS) technologies and / or with satellite method. The estimation method relates the vegetation indices with the final yield at a specific growth stage of the plant (vegetative and reproductive stages) durng the growing season [69][70][71][72].

Remote sensing forms a base for estimating parameters of spatial variability through a very large area frame sample design. It provides an efficient and low-cost stratification based on crop proportion derived from visual interpretation or digital classification of remote sensing data.Remote sensing makes the estimates based on ground surveys near-real time monitoring of crops, very easy derivation of vegetation (covers hilly terrains well) and reduces the amount of field data to be collected [11][73].

When prediction yield using remote sensing, the leaf area index (LAI) is an important variable contributing to determination of the reflectance value of a crop in an image, and as NDVI, which is related to crop vigor and biomass.

5.1 Yield gap between potential and actual yield

In farmers' fields, yields obtained from maize crops (actual or attainable yield) are usually lower than the expected yield (potential yield). A multitude of factors contribute to such yield decreases, and they include poor agricultural policies that restrict affordability and access to production inputs.Other constraints contributing to yield losses in farmers' fields are inadequate or incorrect fertilizer application rates, biotic and abiotic constraints, unavailability of improved seeds, and high cost of labor [53].

6. Conclusion

Yield estimation is critical in any crop production system. The estimation of potential yields takes into account production are, plant density, kernel moisture content and sometimes shelling percentage. In smallholder farms, the estimation of yield is challenging because of continuous planting and use of mixed inter-cropping systems. Nevertheless, maize yield production can be broadly estimated under such conditions. Crop yield simulation models and remote sensing provide government agencies, private industries and researchers the option to estimate yield before harvest and can help farmers to be well prepared for the forthcoming growing season. These methods of yield estimation are expensive and not accurate for small plot sizes. Farmer estimation techniques remain the cheapest and are faster compared to any other methods of field estimation at farmer level.

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