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Research Article

Seasonal Analysis of Maize Production Using DSSAT-CERES Model in Central Rift Valley of Ethiopia

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ABSTRACT

Fertilizer application for crop production under variable climate condition is not well studied in Ethiopia. Models can be used to develop best recommendation based on weather; soil and experimental data in predicting yield and providing agronomic recommendation with climate scenarios. The objective of the study is to develop agronomic recommendation for maize production based on the virtual climate variability with a tool DSSAT model seasonal analysis at Melkassa, Ethiopia. A field experiment was undertaken at Melkassa, to study a combined agronomic strategy with three maize cultivars from Short Season (SS); Medium Season (MS) and Long Season (LS); two irrigation level and eight rates of urea fertilizer treatments were used and all other crop management activities applied uniformly with standard plot arrangement. All measured data on phenology, grain yield and biomass from the field experiment were used for model simulations. These weather scenarios were used in the seasonal analysis program to run each treatment combination with 30-year data. The results of both biophysical and economic analyses of the Seasonal Analysis program predicted an application of medium season cultivar with irrigation water as moisture source and 400 kg/ha urea with 200 kg/ha crop residues as the most dominant management option for maize production at Melkassa Ethiopia. The present study revealed that the generated future weather data were reliable and DSSAT could successfully use it to predict the future crop yields under different management practices and select the best one for sustainable production of maize crops using DSSAT crop models.

Keywords: CERES crop model; DSSAT; Fertilizer recommendation; Seasonal analysis; Yield variability

INTRODUCTION

Maize (*Zea mays L.*) crop become the second most widely cultivated crop and the first in production with smallholder farmers accounting for 94% its production in Ethiopia [1,2]. Maize grain is the most consumed food and very important to smallholder livelihood in Ethiopia. It is one of highly valued crop in the national diet of Ethiopians especially in southern and south eastern regions of the country; it is produced across various agro-ecologies of the country [3]. However, its productivity is constrained by blanket application of mineral nutrients, in particular nitrogen (N). Despite this, maize production is not sufficient and yields remain among the lowest in the world because of different biotic, abiotic and management constraints [4]. Land degradation and declining soil fertility, soil water deficits due to low and erratic rainfall, and inadequate use of good agronomic practices (such as for optimized fertilizer use, soil and water conservation, and maintenance of soil organic matter) are among the constraints [2-6]. Increased climate variability challenges the use of Good Agricultural Practices (GAP) for sustainable intensification and these will need to be well-targeted spatially and temporally to increase maize production [2]. Estimates indicated that current maize yield in Ethiopia could be doubled if improved maize production GAP such as fertilizer use optimization; variety selection and conservation agriculture specific to different maize production situations should have to be widely applied by the smallholder farmers. The means to achieve this could be through identifying and widely applying fertilizer use optimization practices (e.g., crop nutrient response function-based application of optimum nutrient level, appropriate N application time); use of improved crop varieties and conservation agriculture technology (crop rotation, minimum tillage, and crop residue retention) as suitable for heterogeneous maize production zones in Ethiopia.

Identifying the optimum level of management for attaining economically efficient yields remains problematic in agricultural production, and crop simulation models are often found to be useful in this context [7]. Crop simulation models can be used

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as decision support systems to assess the risk and economic impacts of management strategies in agriculture. The Decision Support System For Agro-Technology Transfer (DSSAT) model is a collection of models that connects the decision support system to crop simulation models [8]. The DSSAT model is a software application program that comprises crop simulation models for over 34 crops (as of version 4.7.5) and is used to simulate growth, development and yield as a function of the soil-plant-atmosphere dynamics [8]. The DSSAT model is composed of various crop simulation models which include the CERES models for cereals (barley, maize, sorghum, millet, rice and wheat); the CROPGRO models for legumes (dry bean, soybean, peanut and chickpea); and models for root crops (cassava, potato) and other crops (sugarcane, tomato, sunflower and pasture). These models have been used extensively by researchers, educators, consultants, extension agents, growers, and policy and decision-makers. Applications cover over 100 countries worldwide with a history of more than 20 years.

The other advantage of DSSAT 3.5 is that it has a separate pro- gram driver called Seasonal Analysis, which has the ability to analyses and compare the different management options biophysically and economically to guide choice of the most efficient management option [7]. Many researchers have evaluated these models and predicted phenological parameters, growth and yields [9-11]. The results of these researches reveal that the model can predict crop performance quite well under different management strategies and weather scenarios.

Soil conditions have changed over the years and the old recommendations are not the most efficient today hence the need to update fertilizer recommendations for maize (and other crops) is needed. It is therefore necessary to quickly update fertilizer recommendation for maize using modern tools which will not only evaluate the profitability of crop productions but also the quality of the environment within which crop production is carried out, and combine crop, soil and genetic components of crop production. Decision Support System for Agro-technology Transfer (DSSAT) model is one of such tools.

The aspect of crop simulation models for improving the efficiency of the agricultural systems and to improve profitability is quite unusual but DSSAT features that facility through different program drivers such as the Seasonal Analysis program driver. Thus, seasonal analysis tool was used in selecting the best treatment combination for cultivar; irrigation and urea application rate under the climate of the Melkasa, Ethiopia. The present study was undertaken with an aim to select the management strategies for both ecologically and economically sustainable maize production systems with developed agronomic recommendation with the help of DSSAT model at Melkassa, Ethiopia.

MATERIALS AND METHODS

Description of study site

The field experiment was conducted at Melkassa, which is found 117 km from Addis Ababa, Ethiopia. Geographically located at latitude of 8°4’ North and longitude 39°33’ East on altitude of 1750 masl. Soil parent classified under Andosol and surface texture is Sand loam, drainage type is surface furrows. Crops like Maize; Sorghum; oil crops; pulse and tropical fruits are major crops cultivated in the area.

Planting materials and treatments

The treatment has three factors among which three maize cultivars from short season; medium Season and long Season, used as a Planting material; two level of irrigation (irrigated and rain-fed) and eight rates of urea fertilizer namely 0 kg/ha; 25 kg/ha; 50 kg/ha; 100 kg/ha; 150 kg/ha; 200 kg/ha; 300 kg/ha and 400 kg/ha of urea as a source of N fertilizer; were combined and laid out in (3 × 2 × 8) factorial arrangement. The seed were planted in dry seed method in row arrangement with population density of 5.3 plants per square meter, having inter-row spacing of 75 cm and sowing depth of 5 cm.

DSSAT model

DSSAT version 4.7.5 tools were used for model simulation; soil and weather data of the area and seasonal analysis of 30 years data were simulated starting from the year 1985. Biophysical analysis; Economic analysis and strategic analysis were employed for comparison among treatments; recommendation was formulated and synthesis based on the result of seasonal analysis. To run the model, the initial conditions were used; tillage, organic residue of previous crop (Maize) were incorporated to the field before planting.

RESULTS AND DISCUSSION

Biophysical analysis

Results of biophysical simulation of harvested yield conducted by the DSSAT model over a 30-year period indicate minimum and maximum harvested yield within the 30-year period of simulation with their mean yields and standard deviations. Treatment (Medium season+Rain-fed+400 kg/ha urea fertilizer) recorded the highest yield of 13,602 kg/ha; minimum yield of 3384 kg/ha with a mean yield and standard deviation of 10,119.1 kg/ha and 2137.7, respectively. Followed by the treatment (medium season+fainfed+300 kg/ha urea) having maximum yield of 12,102 kg/ha with mean yield 9836.6 kg/ha and standard deviation 1868.6 kg/ha. Meanwhile, lowest harvested yield was obtained under the treatment (short season variety+irrigated+unfertilized with urea fertilizer) the maximum yield was recorded 1592 kg/ha, whereas we obtained mean yield and standard deviation of 1270.4 kg/ha and 140.1 kg/ha respectively. This, lower yield might be result of nutrient deficiency especially, nitrogen which is one of essential nutrient for the crop. On the other hand, the variety is a short season, poor field established due to lack of nutrient to support growth and development of the crop results lower yield at harvest.

Biophysical analysis of yield and yield components

The box plot show (figures below) the responses of maize to different treatments affect the yield and yield components like harvested yield; biological yield; harvest index; leaf area index and ear weight of maize at Melkassa.

Harvested grain yield

Harvested grain yield obtained (Figure 1) showed a higher variability among treatments in all case, as we can see from the box plot treatment 40 (medium season+rainfed+400 kg/ha) and 39 (medium season+rain-fed+300 kg/ha) have higher lower quartile; median and also upper quartile as compared to the rest of treatments, higher inter quartile. While treatment 1 (short season+irrigated+unfertilized) have minimum variability among lower quartile; median and upper quartile or Inter quartile with recorded lower harvested yield as compared to the rest of the treatments. The result of the model for 30 years showed that the farmer can get higher yield by using medium season variety, and sufficient amount of input (fertilizer) without expending additional money for irrigation even in changing weather condition.

Leaf Area Index (LAI)

Among the various yield components, leaf area index was the one which is affected by application of different treatments in the experiment. The highest leaf area index 4.6 was recorded on treatments LS+irrigated+400 and LS+rainfed+400, thus indicate that type of moisture source, be it irrigation water or rain-fed have no such impact on LAI of maize in this study, but the main determining factors are variety and rate of fertilizers highly affect the plant LAI, long season varieties develop higher LAI as compared to those of short season and medium season varieties, and also leaf growth and development highly determined by rate

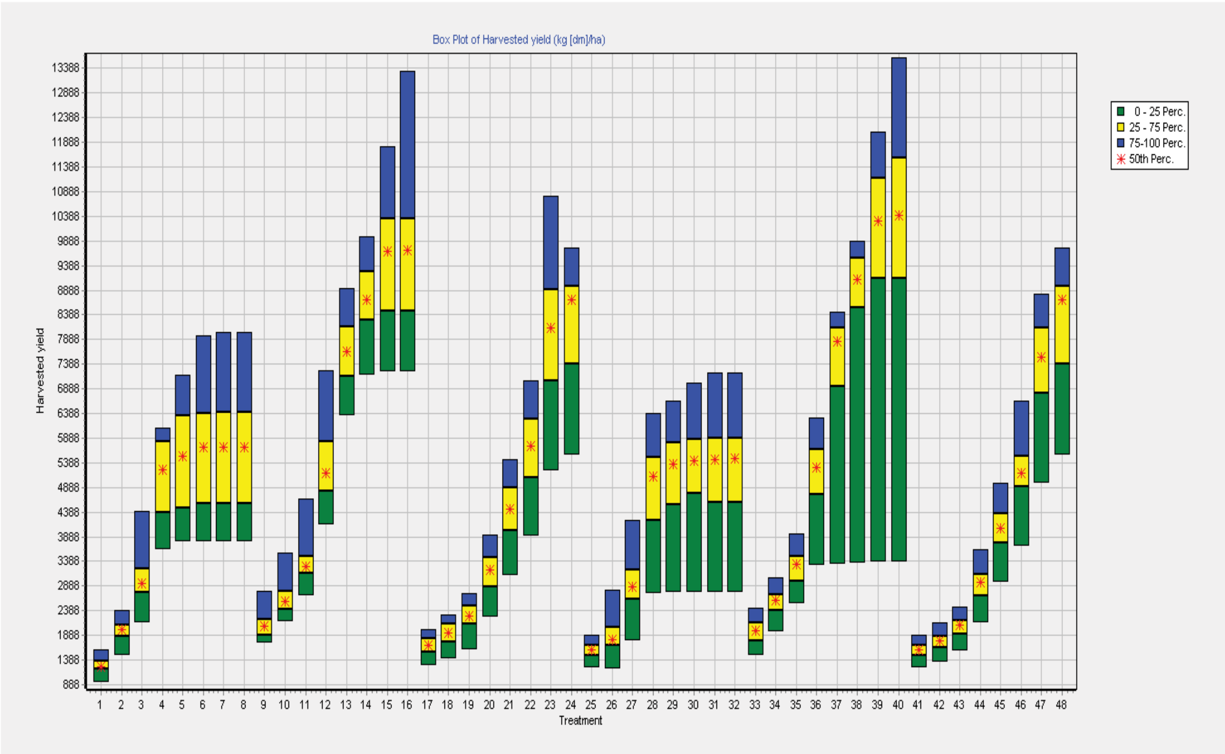

Figure 1: Harvest yield verses N treatments.

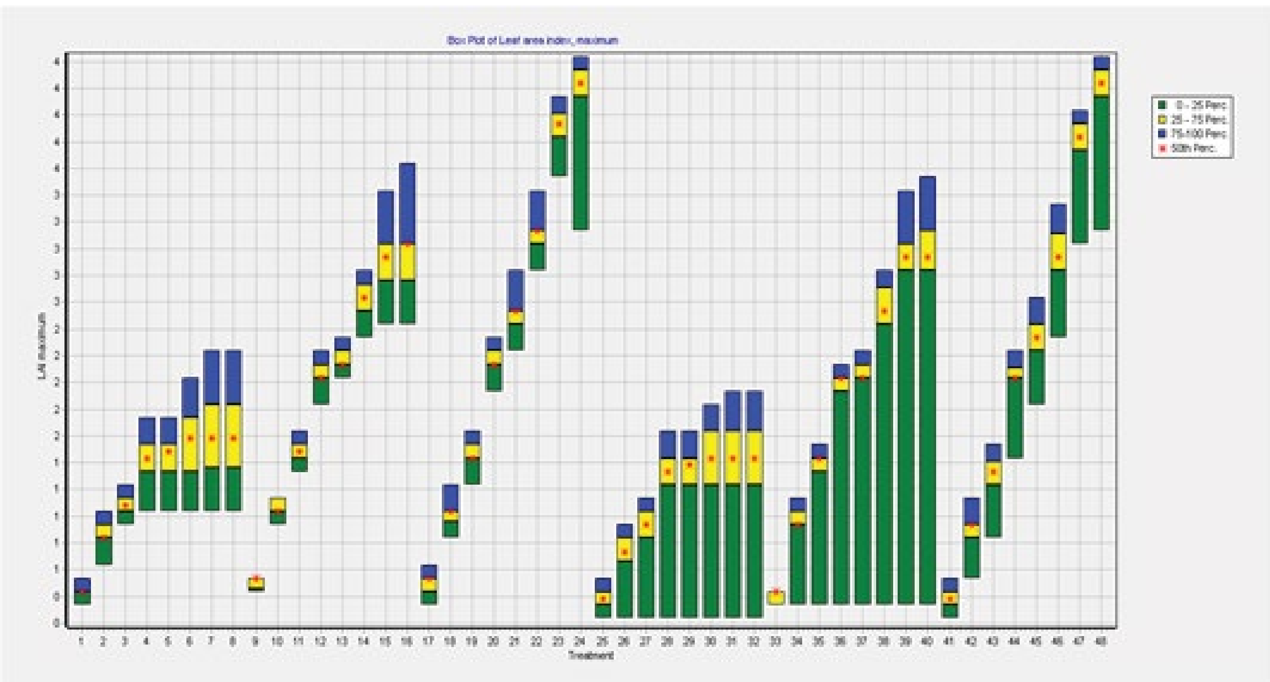

Figure 2: Leaf area index verses N-Rate.

of nitrogen fertilizer, the higher the LAI the higher interception of light for photosynthesis (Figure 2).

Harvest Index (HI)

The physiological efficiency and ability of a crop for converting the total dry matter into economic yield is Known as harvest index. Harvest index of the crop is the factor of biological yield and grain yield, from the mean summary yield and yield components (Appendix Table) result show more or less similar record were observed in terms of HI, but those treatments numbers (40, 39 and 16) have higher grain yield have relatively high HI, in most cases treatments received higher amount of urea per hectare provides large harvest index. This result indicates that grain formation was highly affected by N rate (Figure 3). Since HI is the balance between the productive parts of the plant and the reserves which forms the economic yield, greater improvement in grain yield compared to the corresponding increases in stover yield might have contribute to the increase in harvest index across the increasing levels of N.

Ear weight per plant (kgdm/ha)

This parameter becomes highly affected by the treatment combination; result indicated in the Figure 4. Ear per plant (grain chaff) or eye weight at maturity (kgdm/ha) was higher recorded on treatments (medium season+rain-fed+400 kg/ha; medium season variety+rain-fed+300 kg/ha; and medium season+irrigation+400 kg/ha urea). The box plot indicated lower; median and upper quartile of those treatments obtained higher value, especially medium season varieties are highly responsive with higher amount of urea rate, thus might be the capacity of medium season varieties to convert photo-assimilate from source to sink with in that weather condition and also higher rate of fertilizer help the crop for better growth and development at the early stage of growth and to final anthesis. Whereas lower values were recorded (Appendix

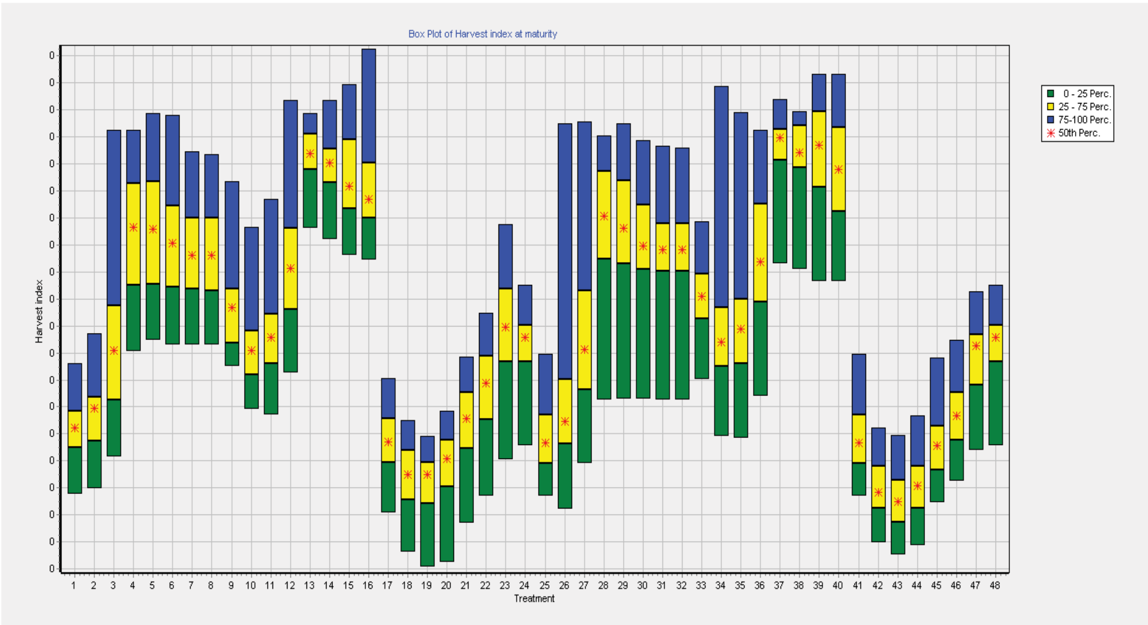

Figure 3: Harvest index.

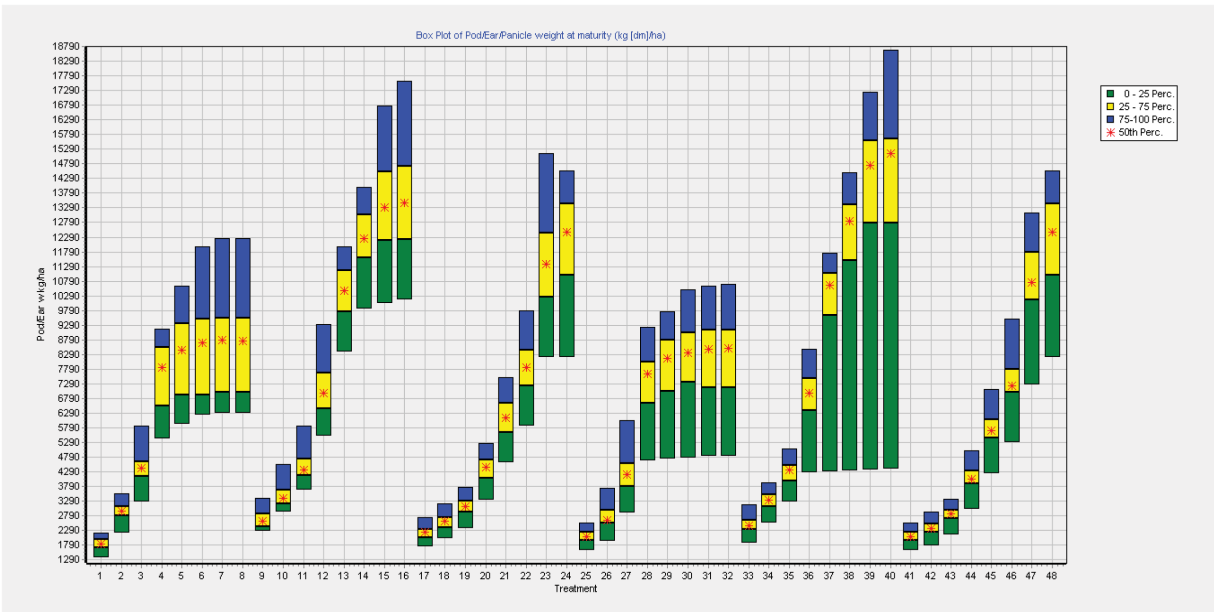

Figure 4: Ear weight.

Table) from treatments (short season variety+irrigation+unfertiliz ed; 25 kg/ha urea and long season+rain-fed+unfertilized also 25 kg/ha urea even medium season variety with unfertilized/lower urea rate of application. This also, might have connection with the soil characteristics of the study area (Melkassa), as well-known clay silty or loam soil of the area is highly fertile, but it has drainage problem, this expose the nutrient to be highly leached from the soil so higher rate of fertilizer become very responsive to the area, to increase yield and yield component of maize.

Grain N content at maturity (kg/ha)

The result indicated that as N-Fertilizer increases grain N content increase consistently, even though the response of N content is slightly affected by cultivar and soil moisture type (irrigated or rain-fed). Figure 5 of box plot indicated that lower variability with in treatments, likewise harvested yield N content become higher when N fertilizer application increases, particularly at rate of 200 kg/ha, 300 kg/ha and 400 kg/ha urea whereas N response among treatments as result of variety and moisture was create slight variability across treatments, however in short season variety with irrigation and short season; medium season variety with rain-fed treatments showed significant variability among inter quartile of the box plot.

Results from cumulative function plot (Figure 6) show treatments short season+irrigated+200 kg/ha urea and short season+irrigated+400 kg/ha urea higher mean harvested yield. Whereas treatment short season variety+irrigation+unfertilized one obtained lower harvested yield, this is due to the limiting factor of N fertilizer even though moisture is supplied sufficiently. Thus, as indicated at 75% cumulative probability the maximum average maize grain yield of 1250 kg/ha, 2250 kg/ha, 3500 kg/ha and 7000 kg/ha were obtained when treatments (SS + Irrigated +unfertilized;

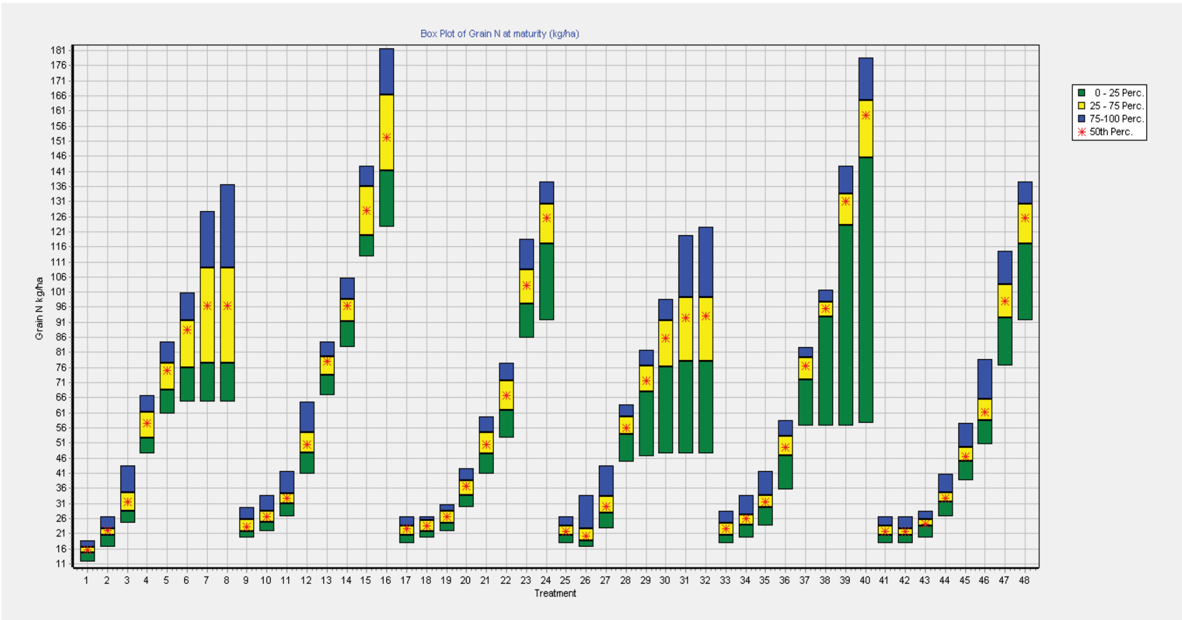

Figure 5: Grain N content with N-rate.

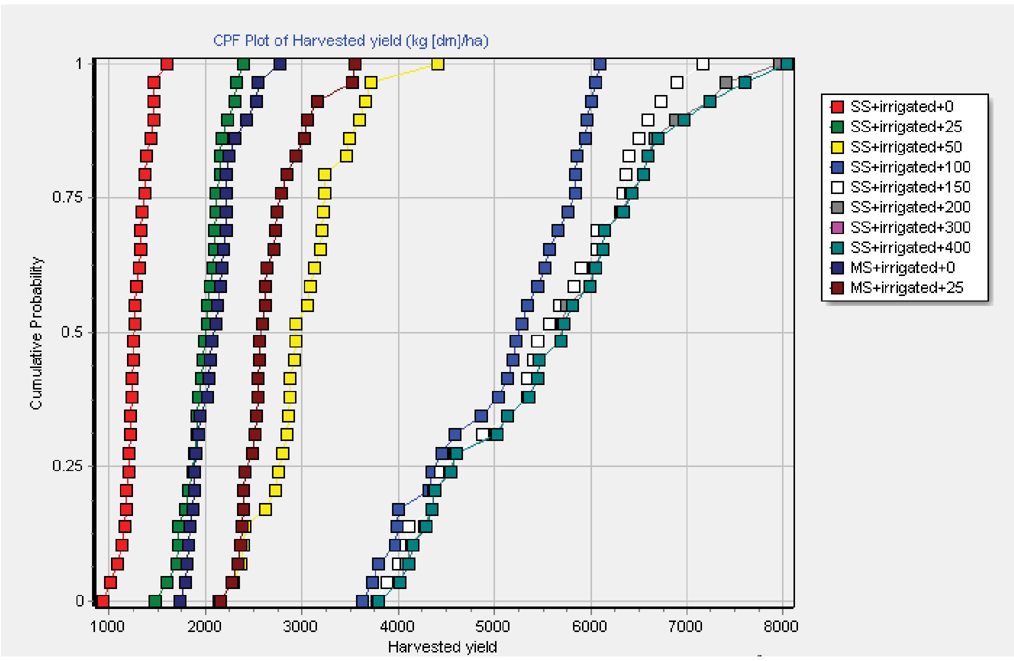

Figure 6: Cumulative probability plot of harvested yield.

SS + Irrigated + 25 kg/ha; MS +Irrigated + unfertilized and SS + Irrigated +400 kg/ha) were applied. This implies that at 75% of the 30-year simulation, no matter the variety; moisture and or fertilizer rate that is employed, maize grain yield cannot exceed 1250 kg/ha, 2250 kg/ha, 3500 kg/ha and 7000 kg/ha on application of treatments (SS+Irrigated+unfertilized; SS+Irrigated+25 kg/ha; MS+Irrigated+unfertilized and SS+Irrigated+400 kg/ha). Even if there might be increment its increment were not economically feasible, because the increment has not significant, beyond 7000 kg/ha the yield become saturated.

Results of variability in attaining predicted average harvest yield is presented in Figure 7. Treatments 1, 41 and 2 present the least variability in obtaining their corresponding average harvested yield. The results showed that when fertilizer was not applied (unfertilized treatments), obtainable yield range is limited but increases when fertilizer is applied (Figure 7). Treatment 40 (medium season+rainfed+400 kg/ha urea) showed a obtaining higher harvest yield with high variance followed by treatment 39 (medium season+rain-fed+300 kg/ha urea) and treatment 16 (medium season irrigated+400 kg/ha urea) this indicated that N fertilizer is the most limiting factor especially for those medium season and long season cultivars to utilized efficiently, Therefore treatments with higher average harvest yield with less variability in obtaining them are considered the best. Treatment 40 recorded the highest mean yield and variation of 10,000 kg/ha and 4,500,000 kg/ha respectively.

Economic analysis

The results from economic analysis showed that treatment 40 (Medium Season Cultivar (MSC)+rain-fed+400 kg/ha urea) provide highest money in terms of farm return, about 2706.92 $/ha was obtained with standard deviation of 712.55, followed by treatment 39 (Medium Season+rain-fed+300 kg/ha) and treatment 16 (medium season+irrigated+400 kg/ha urea) provided 2631.16 $/ha and 2577.31 $/ha respectively. However, in most case treatments (SS (Short Season)+rainfed+0; MS+rainfed+0 and LS(Long Season)+rainfed+0) which are not fertilized and also even those treatments fertilized with lower (25 kg/ha) with urea resulted the lowest return when produced in rain-fed condition on the other hand those treatments (SS+irrigated+unfertilized and LS+irrigated+unfertilized) that are produced with irrigation water and unfertilized was provided negative mean return because the production cost with irrigation water is higher than the profit we obtained from those treatments. Thus, show that fertilizer especially N fertilizer is the most yield and economic limiting factor in maize production.

Strategic analysis

The strategic analysis from Mean-Gini dominance values showed that from 48 treatment combinations, the economic strategic analysis for the 30 years showed that treatment medium season variety+rain-fed+400 kg/ha urea is efficient treatment among the rest of treatment. The analysis could successfully differentiate and assess the grain yields under different treatment of variety, moisture and N rate of applications. Treatment 40 (medium season+ rain-fed+400 kg/ha urea) were economically superior combined variety, moisture and urea fertilizer recommendations as they presented the highest return to investment per hectare and the highest efficiency (Table 2). There was a similar result observed between variety, irrigation and fertilizer (urea) rates determined from the seasonal and biophysical analysis and the economic analysis for the study site, Melkassa. As the model utilized 1985-2014, 29 years of weather data for the selection of management strategies for a maize production system through economic analysis, the mean return and Gini dominance (mean return-Gini coefficient) value of treatment 40 is higher among treatments, 2706.9 $/ha and 2321.4 $/ha respectively.

Strategy analysis: Mean-Gini Dominance: E(x) mean return $/ha, F(x) Gini Coefficient $/ha

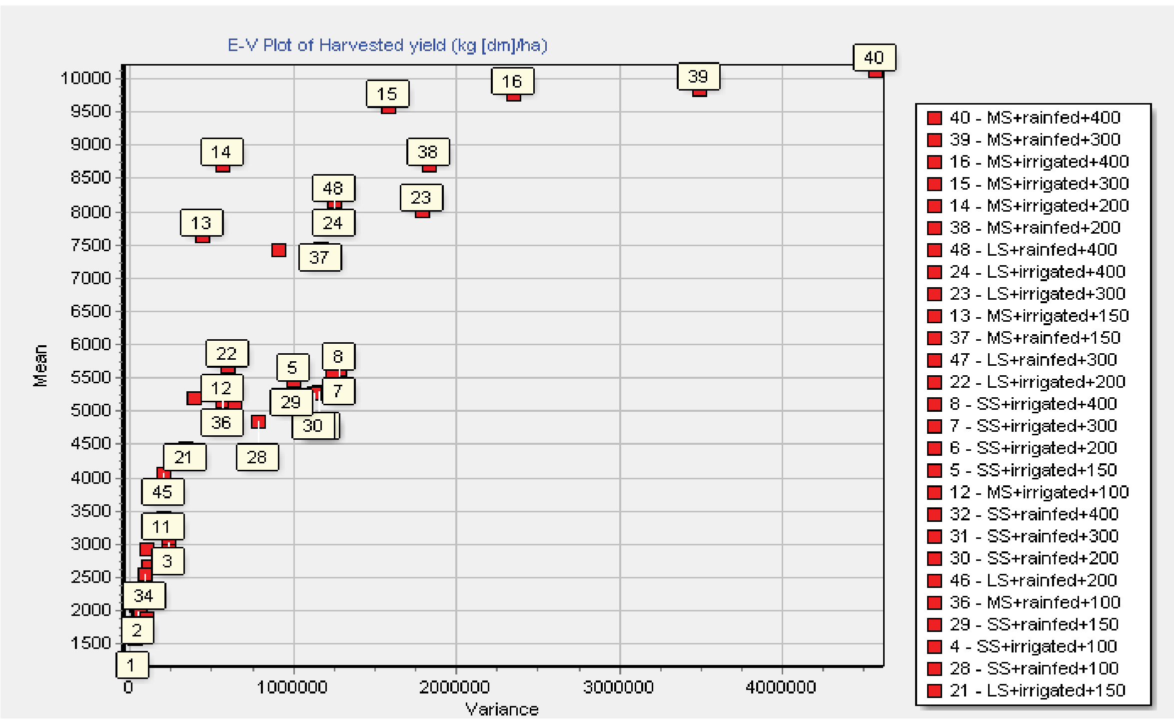

Figure 7: Mean-variation of harvested yield in (kg/ha).

Table 1: Strategic analysis of treatments efficiency.

Treatment	Field	E(x)	E(x)-F(x)	Efficient
MZ SS+irrigated+0	EIMK000001	-162.4	-188.6	No
MZ SS+irrigated+25	EIMK000001	66.7	25.8	No
MZ SS+irrigated+50	EIMK000001	404.5	314.5	No
MZ SS+irrigated+100	EIMK000001	1079.4	926.6	No
MZ SS+irrigated+150	EIMK000001	1189.4	995.1	No
MZ SS+irrigated+200	EIMK000001	1230.6	1014.9	No
MZ SS+irrigated+300	EIMK000001	1218.2	999.2	No
MZ SS+irrigated+400	EIMK000001	1199.5	980.4	No
MZ MS+irrigated+0	EIMK000001	114.1	68.2	No
MZ MS+irrigated+25	EIMK000001	292.6	232.8	No
MZ MS+irrigated+50	EIMK000001	532.1	452	No
MZ MS+irrigated+100	EIMK000001	1160.1	1020	No
MZ MS+irrigated+150	EIMK000001	1910.8	1781.4	No
MZ MS+irrigated+200	EIMK000001	2261.5	2115.7	No
MZ MS+irrigated+300	EIMK000001	2536.2	2292.6	No
MZ MS+irrigated+400	EIMK000001	2577.3	2287.4	No
MZ LS+irrigated+0	EIMK000001	-36.2	-74.2	No
MZ LS+irrigated+25	EIMK000001	35.6	-11.7	No
MZ LS+irrigated+50	EIMK000001	145.7	90.5	No
MZ LS+irrigated+100	EIMK000001	438.4	358.1	No
MZ LS+irrigated+150	EIMK000001	827.6	713.6	No
MZ LS+irrigated+200	EIMK000001	1225	1074.6	No
MZ LS+irrigated+300	EIMK000001	1993.2	1734.6	No
MZ LS+irrigated+400	EIMK000001	2212.6	1926.5	No
MZ SS+rainfed+0	EIMK000001	-186.6	-225.9	No
MZ SS+rainfed+25	EIMK000001	40.9	-18.1	No
MZ SS+rainfed+50	EIMK000001	375.3	285.3	No
MZ SS+rainfed+100	EIMK000001	1008.9	842.4	No
MZ SS+rainfed+150	EIMK000001	1082.7	895.1	No
MZ SS+rainfed+200	EIMK000001	1127	928.1	No
MZ SS+rainfed+300	EIMK000001	1113.6	911.3	No
MZ SS+rainfed+400	EIMK000001	1096.3	894.3	No
MZ MS+rainfed+0	EIMK000001	72.5	23.8	No
MZ MS+rainfed+25	EIMK000001	256.3	199	No
MZ MS+rainfed+50	EIMK000001	484.8	413.4	No
MZ MS+rainfed+100	EIMK000001	1109.3	966.1	No
MZ MS+rainfed+150	EIMK000001	1862.5	1689.1	No
MZ MS+rainfed+200	EIMK000001	2269.8	2061.5	No
MZ MS+rainfed+300	EIMK000001	2631.2	2311.2	No
MZ MS+rainfed+400	EIMK000001	2706.9	2321.4	Yes
MZ LS+rainfed+0	EIMK000001	-54.6	-86	No
MZ LS+rainfed+25	EIMK000001	-4.7	-39.3	No
MZ LS+rainfed+50	EIMK000001	94	53.9	No
MZ LS+rainfed+100	EIMK000001	365.3	305.3	No
MZ LS+rainfed+150	EIMK000001	731.2	645.2	No
MZ LS+rainfed+200	EIMK000001	1102	986.5	No
MZ LS+rainfed+300	EIMK000001	1826.4	1645.7	No
MZ LS+rainfed+400	EIMK000001	2056.2	1846.3	No

CONCLUSION

The field experiment using DSSAT seasonal analysis can accurately simulate maize response to different treatments (cultivar; irrigation and rate of fertilizer) for recommendation in changing climate condition of the earth. The result from both the economic and strategic analysis showed that prediction by DSSAT through seasonal analysis is quite reasonable in selecting the most suitable treatment combination of variety; irrigation and fertilizer rate for the study area. From the predicted results of strategic and economic analysis suggested that the application of medium season variety; using rain-fed as moisture source and 400 kg/ha urea fertilizer for Nitrogen source provides the best economic yield of maize and the most efficient one among treatments. The results of both strategic and economic analyses showed that the prediction by DSSAT through seasonal analysis is quite reasonable in selecting the most suitable treatment combination of variety, irrigation and fertilizer rate for Melkassa site. The predicted results of strategic and economic analyses suggested that the application of medium season variety; with rain-fed and 400 kg/ha urea fertilizer was the best combination of management options for the maximum economic yield of crop. Generally, in all case of seasonal analysis, biophysical; economic and strategic analysis treatment 40 become the better performer over the other factors; like short season and long season cultivar the medium season cultivar is the best with rain-fed condition using high rate of urea fertilizer, the 30-year weather condition shows also tells their exist sufficient rain fall for maize production in the area, thus help in reduce cost of production, basically no need of irrigation cost. The result indicates high response of maize yield in higher application rate to 400kg/ha of urea, the economic analysis ensures that one can get 2706.92 $/ha return as compared a -162.40 $/ha of treatment one (SS+Irrigated+unfertilized) with net benefit of 2869.32 $/ha where as a 2634 $/ha net benefit over treatment 33 (MS+rain-fed+unfertilized).

FUTURE RECOMMENDATION

- Based on 30 years weather data, treatment combination of medium season variety, Irrigation as moisture source and 400 kg/ha of urea as N fertilizer source is the best to be used in Melkassa area for maize production
- Use of three times split application of urea provide increase maize yield, help efficient utilization of the nutrient by the plant

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