Agricultural Journal 2 (4): 514-519, 2007

Production Functions and Their Use in Predicting Chickpea Biomass Yields When Grown under Varying Tillage and Sowing Dates in Naivasha, Kenya

A.M. Kibe and C.N. Onyari
Department of Crops, Horticulture and Soils,
Egerton University, P.O. Box 536, Njoro, Kenya

Abstract: The use of production functions as tools for analyzing agronomic relationships and crop growth is gaining importance the world over. Their predictive value in crop adaptation trials for specific agro-ecological sites particularly in semi arid lands is of special interest, but little, if any work is being done with this regard in Kenya. A chickpea (Cicer arietinum L.) cultivar, ICCV 95423 was therefore planted under four tillage systems namely, Conventional (CT), Double Digging (DD), Furrow (FT) and Strip Tillage (ST) and under three sowing dates (two weeks apart) at Naivasha. The aim was to develop evapotranspiration and biomass yield (ET-yield) relationships and determining their potential use in analyzing growth (LAI and DM production) of chickpea. Estimated yields (computed) were produced using the 1st season's (Jan-May '05) functions and validated with the 2nd season (Jun-Oct '05) actual yield data sets. The relationships exhibited very high regression correlation coefficients (R^2>0.93) indicating the potential reliability of the functions in predicting chickpea yields. Rate of increase in biomass production per hectare millimeter increase in water use was 17.5kg ha-mm^{-1}. Biomass yields estimated from season II ET data were validated and had a reliability of 0.859 and 0.952 when linear and curvilinear functions were fitted, respectively. The January to June crop produced DM at a higher rate of 685.2 kg ha^{-1} per unit LAI as compared to 309 kg ha^{-1} LAI^{-1} for season II crop. Quadratic functions proved able to account for more variations in DM production than linear functions. They can therefore, be used reliably in analyzing and predicting DM production of chickpea in Naivasha. Chickpea has great agronomic potential for use as a food and forage crop in the dry highlands of Kenya.

Key words: Production, functions, chickpea, biomass, evapotranspiration

INTRODUCTION

Chickpea is a drought-tolerant, cool-season legume. It's used for human consumption in normal meals or as a health food due to its high protein content; large-seeded kabuli type are sold for canning purposes; milled into flour and used for baking and making snacks or as fodder crop (Oweis *et al*., 2004; Nielsen, 2001).

In the Kenyan dry highlands of Naivasha (>1900 m above sea level) farmers subsist on maize-bean cropping systems which normally yield poorly due to the low and erratic annual rainfall of less than 650 mm. These crops are grown mainly on small-scale farms during the April to July long rain season which are unreliable, resulting in low and variable yields. The later shorter rains (October to December) are highly unreliable and land is normally left fallow for grazing purposes. There is no literature on chickpea's production potential in the Naivasha dry highland regions of Kenya. Gradient irrigation studies with chickpea in Yellowjacket, CO (elevation of 2128 m) showed a strong yield response to water applied, but the response was not consistent from year to year. Overall yields ranged from 4.8-9.6 kg ha^{-1} for each additional millimeter of water applied (Brick *et al*., 1998). A production fact sheet for South Australia reports a chickpea yield increase of 15.0 kg ha^{-1} for each additional millimeter of growing season precipitation received (PIRSA, 2000). Singh (1984) and Rahman *et al*. (1983) however, found no consistent relationship between water use and yield. Whereas Nielson (2001), reported linear increases in seed yield with increases in water use. He noted that the strongest linear response (r^2 = 0.81) was for the chickpea relationship as compared to that of field pea and lentil. He concluded that the combination of high growing season rainfall and lack of excessively high temperatures during the flowering and grain-filling periods resulted in these very high rain fed yields on chickpea. Chickpea yields ranged from 600-3500 kg ha^{-1} with 220-420 mm of water use. Chickpea was observed to give the greatest response to increased water use, with a mean of 10.6 kg ha^{-1} for each millimeter increase in water use.

Corresponding Author: A.M. Kibe, Department of Crops, Horticulture and Soils, Egerton University, P.O. Box 536, Njoro, Kenya

Although the productivity of any crop species depends on its genetic potential, it is the environment and/or the production system management applied that determine the realization of this potential (Oweis *et al.*, 1999). Water is the most crucial factor influencing crop yield. Tillage is known to influence soil physical characteristics and therefore affect infiltration, percolation and ultimately the amounts of water stored in soil profile. Sowing at the right time therefore permits higher moisture use where sufficient rainwater is available for crop uptake. Generally, relationships between crop yield and water are expressed in terms of transpiration, evapotranspiration or field water applied (Oweis *et al.*, 2004; Kibe *et al.*, 2006). There is a strong correlation between yield and seasonal evapotranspiration or crop water use. The relationship is normally linear. Yield verses seasonal Evapotranspiration (ET) also plots as a straight-line relationship. However, this relationship or line tends to intersect the ET-axis to the right of the origin by an amount related to soil evaporation (Oweis and Hachum, 2003; Oweis *et al.*, 2004). Due to uncontrolled water losses and inefficiency of irrigation, crop yield verses amount of applied water typically plots as a nonlinear relationship and is usually parabolic. More comprehensive crop production functions that take into account other variables are available in literature; but most, if not all, are site specific (Oweis *et al.*, 1999). The predictive potential of chickpea crop production functions for Kenyan dry highland environments have yet to be studied. Therefore, this study was carried out to evaluate the predictive potential of functional relationships for leaf area index and above ground biomass with water use (ET), as influenced by varying tillage practices and sowing dates in Naivasha, Kenya.

MATERIALS AND METHODS

Water use (evapotranspiration) was calculated by the water balance method using soil water measurements and assuming runoff and deep percolation to have been negligible (plot area slope was <0.5% and water table more than 7 m). Amounts of growing season precipitation were measured by an automatic weather station. Season I (Jan-Jun) and II (Jun-Oct 2005) received 208 and 140 mm rainfall only. Irrigation water of about 70 mm was applied 11 Days After Sowing (DAS) to supplement the rain so as to initiate uniform germination of first sowing in both seasons. Soil water measurements were made at planting, 35,63,77,91,119 and at 133 (harvest) at each of the 36 sample sites using a neutron probe at soil depths of 10, 20, 30, 44, 60, 80, 110 cm. At physiological maturity, samples were harvested and threshed manually. Sample area was 9. m^2, centered on each soil water measurement site. Linear and quadratic regressions were fitted on all water use and biomass yield/LAI data collected to determine the production functions (yield vs. water use). These production functions were used with the second year ET/biomass/LAI data sets, to obtain estimated yield data, which was then related with the actual data sets and a 1:1 line fitted to evaluate yield variability.

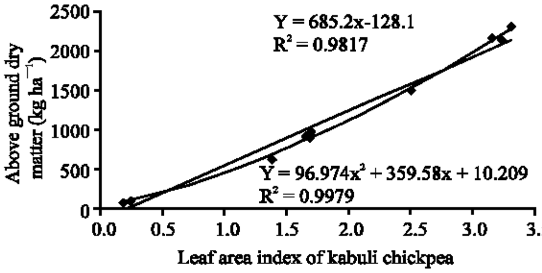

Fig. 1: Relationship of leaf area index and above ground dry matter for chickpea in season I

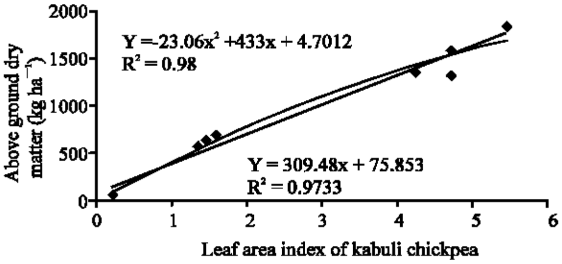

Fig. 2: Relationship of leaf area index and above ground dry matter for chickpea in season II

RESULTS AND DISCUSSION

Relationship of leaf area index and above ground biomass as affected by tillage and sowing dates: An attempt was made to relate above ground Dry Matter (biomass) yields (DM) observed (and as influenced by the tillage and sowing date combination effects), with the leaf area indices measured, up to early pod formation stages (91 DAS). Results revealed that Leaf Area Indices (LAI) increased with maturity of the chickpea to attain a maximum at 91 DAS in both seasons. Beyond this date (reproductive), LAI declined drastically with maturity due to leaf senescence and fall.

Tillage and sowing date practice combination effects at different stages of crop growth (and up to 91 DAS) revealed varied effects on the LAI and thus DM production of chickpea. Above ground biomass was seen (Fig. 1 and 2) to increase linearly with increase in leaf area indices in both seasons, with very high regression coefficients of 0.982 and 0.973 for seasons I and II, respectively. This signifies the reliability of this function in explaining the dependence of DM on expansive leaf area with time. In the January to May season, dry matter accumulated at the rate of 685.2 kg ha^{-1} per unit LAI. Dry matter accumulation in the June to October second sowing was slower at 309.5 kg /ha per unit LAI expansion. The Jan-May/June crop (Season I) expressed an indeterminate growth habit, because of the later rains received during the reproductive phase of chickpea growth. Therefore, the faster growth observed for season I crop was probably due to the higher total precipitation received over the early vegetative growth phase of the chickpea crops thereby enhancing higher crop growth which resulted in higher expansive leaf growth and DM accumulation as maturity progressed. In the second season crop (Jun-Oct) however, rains subsided in late August causing the crop to stop vegetative growth and enter the reproductive phase earlier. This agrees with Oweis *et al.* (2004) who stated that earlier crop growth results in higher leaf area and therefore, more photosynthesis, biomass production and growth during the period where there is a lower vapor pressure deficit.

The DM yield-LAI relationship could be explained better when the data was fitted with quadratic curves in both seasons. In season I (Fig. 1) the biomass accumulation was observed to continue increasing with expansion of leaf area, as opposed to the lowering in rate of DM accumulation with increasing LAI in season II (Fig. 2), beyond a LAI of 3. The regression functions could account for 99.8 and 98.0 % of the variations, which was slightly better than that for the linear relations. The curvilinear curves and functions are therefore better fits than the linear functions in explaining the response of chickpea DM production to expansive leaf growth. These quadratic functions reveal that there is a second factor that limits/influences the relationship particularly at higher leaf area indices and under the given environmental limits (i.e., rainfall, temperature, vapor pressure deficit, etc.). These relationships are governed by the genotype–environment interactions that the chickpea cultivar characteristically responds to and is thus, reflected by the regression coefficients displayed in the functions. These coefficients become an important component in deterministic crop production models that aim at predicting or simulating yield outcomes for different cropping ecologies.

The validity of the functions in predicting yield output was tested by relating second year actual DM yields to DM yields computed from the first season LAI data set and production functions. The scatter points could be evaluated with a 1:1 line as given in Fig. 3 and 4. The quadratic function's computed DM was a better predictor than the linear function ones, which reveals a slight overestimation, particularly at lower LAI values. At higher LAI values, there was more scatter of data points which means that there is higher variability in response of chickpea DM accumulation at maximum leaf expansion. This variation could result from various crop management and environment influences i.e., crop pest and diseases that may affect the effectiveness of maximum leaf area expansion potential in assimilate production and partitioning.

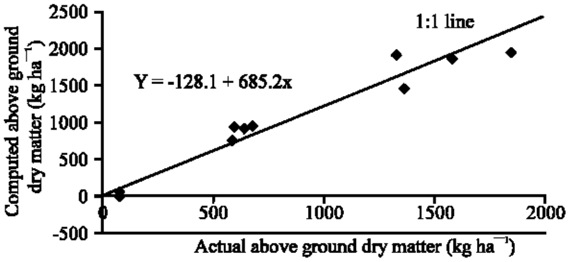

Fig. 3: Validation of computed and actual data sets for above ground biomass (kg ha^{-1}) as affected by LAI in chickpea

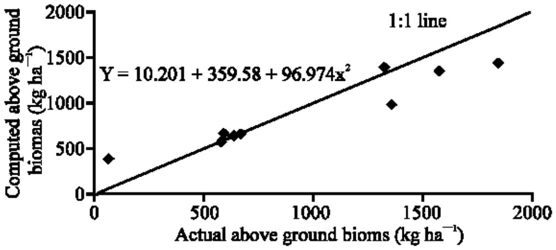

Fig. 4: Validation of computed and actual data sets for chickpea's above ground biomass (kg ha^{-1})

Relationship of evapotranspiration and above ground biomass under varying tillage and sowing dates: Results of this study revealed that at crop maturity, the total seasonal Evapotranspiration (ET) ranged between and 321.7 and 338.8 mm, in season I (Jan to June 2005), a difference of over 17 mm water use. In the second season (June-Oct 2005), the total seasonal ET ranged from 298.3 to 302.3 mm, a difference of 4 mm water use only. The narrow range in ET in season two was due to the less water received (278 mm) by crop and the combined effects of tillage and sowing date treatments (which modified available soil water), as compared to that received in season II (210 mm).

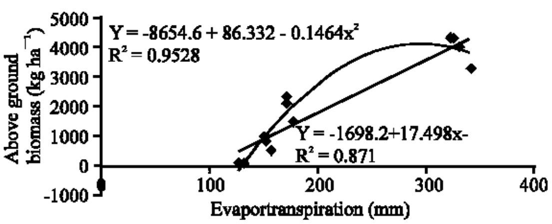

Fig. 5: Tillage effects on relationship of evapotranspiration (mm) and biomass production (kg ha^{-1}) by chickpea at Naivash in season I

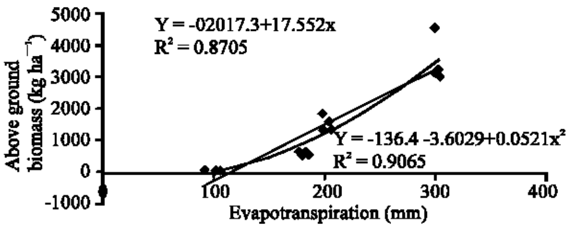

Fig. 6: Tillage effects on relationship of evapotranspiration (mm) and biomass production (kg ha^{-1}) by chickpea at Naivash in season II

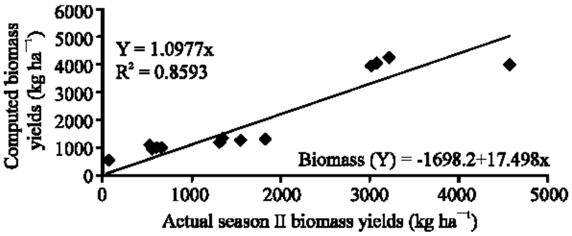

Fig. 7: Validation of computed to actual biomass yields (kg ha^{-1}) from season I evapotranspiration data set

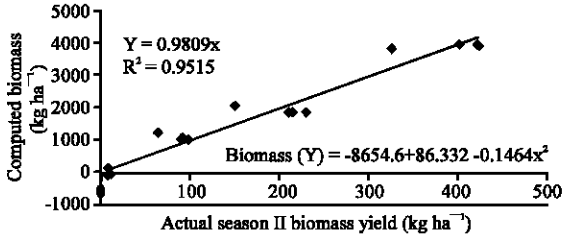

Fig. 8: Validation of computed to actual biomass yields (kg ha^{-1}) from season I ET evapotranspiration data set

The relationships of ET to above ground Dry Matter (DM) yield for seasons I and II are given in Fig. 5 and 6, respectively. The rate of increase in chickpea biomass per increase in ET was approximately 17.5 kg ha^{-1} mm^{-1} water used (or 1.75 kg ha^{-1} m^{-3} of water use) as given by the linear functions for both seasons. This was higher than 9.6 kg ha^{-1} mm^{-1} reported by Brick *et al.* (1998) and 10.6 kg ha^{-1} mm^{-1} of water use reported by Nielson (2001), but close to 15 kg DM ha^{-1} mm^{-1} reported from Australia (PIRSA, 2000). The regression correlation coefficients were high at approximately 0.871 for both seasons. Zang *et al.* (2004) noted that yield versus seasonal evapotranspiration also plots as a straight line relationship The linear relationship was found to be the most appropriate by Oweis *et al.* (2004) for winter chickpea-early sown (late November) and grown in rotation with wheat. The resulting best fit linear equations for both grain and biomass yields gave relatively low values of ET at zero yield compared to that of Zang *et al.* Also, the correlation coefficients for the grain and biomass yield were 0.59 and 0.62, respectively. To improve the production function, the regression analysis was performed on the data of each sowing date separately. The resulting equations gave a notably higher correlation and more realistic values of ET at zero yields ranging from 48-95 mm with an average value of 73 mm. In the present study however, quadratic functions were found to be better fits than linear ones, with 0.95 and 0.91 dependability in respectively seasons. The linear relationship or line tended to intersect the ET-axis to the right of the origin by an amount related to soil evaporation (Oweis and Hachum, 2003), which in our present study ranged between 112 and 125 mm water evaporated at zero yield. Due to uncontrolled water losses and inefficiency of irrigation, crop yield versus amount of applied irrigation water typically plots as a nonlinear relationship and is usually parabolic (Oweis *et al.*, 2004). The quadratic relationships were therefore able to explain and or predict the continued growth of chickpea in later stages of growth and at higher ET. The higher yields given by the first season chickpea, as compared with the second season sown crop, appear to be the result of increased biomass production occurring as the result of a longer period of vegetative growth occasioned by the rains received over pod filling stage. This was in agreement with the findings of Keatinge and Cooper, (1983), Saxena (1984), Saxena (1987) and Oweis *et al.* (2004).

Validation of ET- biomass yield production functions proved to be highly reliable as shown in Fig. 6 and 7 for seasons I and II, respectively. The linear and quadratic functions developed from season I data set were used to generate (computed) biomass yields with season II evapotranspiration data sets. The 1:1 line fitted reveals a predictability accuracy of over 85.9 and 95.2%, for the respective functions. This shows the higher predictive value of quadratic production functions as compared to linear functions. Kang *et al*. (2001) noted from their findings that the relationships between crop yield and seasonal ET can take different forms and the empirical coefficients vary with climate, crop type and variety, irrigation, soil texture, fertilizer and tillage methods. Therefore, more studies are recommended to determine crop production functions for various crops when grown under varying agro-ecological zone of Kenya (Fig. 8).

Inference drawn from the quadratic functions reveal that in the first season maximum biomass yields can be obtained with about 280 mm of water use (Fig. 5) while in season two the increase in ET beyond 250 mm and above showed and increasing trend in DM accumulation (Fig. 6). The reliability of this function was however lower (91 %) as compared to that from season II (95.3 %). The higher variation in DM production per unit increase in water use (mm) at higher ET values for second season (which was similar to the LAI-DM relationship given above), was probably caused by tillage variables, which would have modified soil moisture storage. This would therefore have varied the available water content, which would consequently have influenced the DM production, at later stages of crop growth, which fell under reducing moisture availability. Therefore, under dry land conditions, the effort to increase chickpea's DM production is only certain when accompanied by expansive leaf growth of the crop in an environment that permits enhanced evapotranspiration.

CONCLUSION

Tillage and sowing date combination effects caused more variation in water use (ET), LAI and rates of DM accumulation in the January to June season (I) as compared to the second (June to October) season.

The range of water used by the crop (212-339 mm) in season I was higher as compared to the shorter range of water used (208-302.3 mm) in season II. This variation was attributed to the effects of imposed tillage and sowing dates treatment combinations and as influenced by the rainfall received in respective seasons.

Quadratic production functions relating LAI or ET to biomass production were better predictors of DM production than the linear functions fitted.

The validity of these functions in predicting DM production was high. Therefore, they can be used in predicting biomass production (DM) of Kabuli chickpea from measured ET values in Naivasha region.

Grain yield to ET relationships would reveal the extent of functions reliability in prediction of grain yields for the region. Further research work to validate these functions in diverse sites of Naivasha is therefore needful.

Development and recommendation of appropriate agronomic production systems for cultivars that enhance leaf area expansion and rates of DM accumulation under limited and adequate water regimes (ET) is highly recommended.

ACKNOWLEDGMENT

I am thankful to the Deputy Vice Chancellor Research and Extension, Egerton University, for providing part of the research funding and the director NAHRC, KARI, Naivasha station for providing facilities for carrying out this research work.

REFERENCES

Brick, M.A., A. Berrada, H.F. Schwartz and J. Krall, 1998. Garbanzo bean production trials in Colorado and Wyoming. Colorado State University Agriculture Exp. Stn.

Kang, S., L. Zang, Y. Liang and H. Cai, 2001. Effect of Limited Irrigation on Yield and Water Use Efficiency of Winter Wheat on the Loess Plateau of China. In McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (Eds.), Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia, ACIAR, 84: 105-116.

Kibe, A.M., S. Singh and N. Kalra, 2006. Water-nitrogen relationships for wheat growth and productivity in late sown conditions. Agric. Water Manage., 84: 221-228.

Keatinge, J.D.H. and P.J.M. Cooper, 1983. Kabuli chickpea as a winter-sown crop in northern Syria: moisture relations and crop productivity. J. Agric. Sci., (Cambridge), 100: 100 667-680.

Nielsen, David C., 2001. Production functions for chickpea, Field Pea and Lentil in the Central Great Plains Agron. J. Am. Soc. Agron., 93: 563-569.

Oweis, T., A. Hachum, M. Pala, 2004. Water use efficiency of winter-sown chickpea under supplemental irrigation in a Mediterranean environment. Agric. Water Manage., 66: 163-179.

Oweis, T. and A. Hachum, 2003. Improving Water Productivity in the Dry Areas of West Asia and North Africa. In: Kijne, W.J., Barker, R., Molden, D. (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI Publishing, Wallingford, UK., pp: 179-197.

Oweis, T., A. Hachum, J. Kijne, 1999. Water harvesting and supplemental irrigation for improved water use efficiency in dry areas. SWIM Paper No. 7, System-Wide Initiative on Water Management. International Water Management Institute, IWMI, Colombo, Sri Lanka.

[PIRSA] Primary Industries and Resources South Australia. 2000. Field crops: Pulses, oilseeds and other crop production-technical information [Online]. Available at http://www.pir.sa.gov.au/ dhtml/ss/ section.php?sectID=332andtempID=11 (verified 3 Jan. 2001).

Rahman, S.M., M. Shamsul Alam and M. Ahmed, 1983. Water relations and yield of two chickpea (*Cicer arietinum* L.) cultivars as influenced by different levels of irrigation. Thai J. Agric. Sci., 16: 253-265.

Saxena, M.C., 1984. Agronomic Studies on Winter Chickpeas. In: Saxena, M.C., Singh, K.B. (Eds.), Proceedings of the Workshop on Ascochyta Blight and Winter Sowing of Chickpeas, ICARDA, Aleppo, Syria, pp: 123-137.

Saxena, M.C., 1987. Agronomy of Chickpea. In: Saxena, M.C., Singh, K.B. (Eds.), The Chickpea. C.A.B. International, Wallingford, UK, pp: 207-232.

Singh, G., 1984. Water use in chickpea as affected by irrigation scheduling in semi-arid region. Trans. Indian Soc. Desert Tech., 9: 58-61.