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*Original scientific paper*

# PATH ANALYSIS OF THE PRODUCTIVE TRAITS IN *SORGHUM* SPECIES

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This research studied the phenotypic correlation coefficients between three *Sorghum* species, namely forage sorghum *S. bicolor* Moench. (c. *NS-Džin*), Sudan grass *S. sudanense* L. (c. *Zora*) and interspecies hybrid *S. bicolor* x *S. sudanense* (c. *Siloking*). The analyses were performed on plant material samples taken from the first cutting, when plants were in the beginning phase of tasseling. The following morphologic traits were studied: plant height, number of leaves per plant, stem leaf weight and mean stem weight. Additionally, their direct and indirect effect on dependent variable green biomass yield was analysed, for which path coefficients were calculated. This method enables more quality and full insight into relations existing among the studied traits, more precise establishment of cause-effect connections among them, as well as to separate direct from indirect effects

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of any particular trait on dependent variable, being biomass yield in this case. The analysis of phenotypic coefficients revealed differences in direct and indirect effect of certain traits on dependent variable. Sudan grass had the highest stem (2.281 m) and most leaves per plant (7.917). Forage sorghum had the largest leaf weight per plant (49.05 g), while interspecies hybrid had the highest mean stem weight (80.798 g). Variations of these morphologic traits among species were found to be significant and very significant.

Morphologic traits - stem height and weight significantly affected sorghum green biomass yield. Leaf number and leaf portion in total biomass were negatively correlated with yield. Cultivars differed significantly regarding morphologic and productive traits. Sudan grass had the lowest green biomass yield, while forage sorghum and interspecies hybrid had significant yield increase.

*Key words*: cultivar, forage sorghum, interspecies hybrid, path analysis of phenotypic coefficients, Sudan grass.

## INTRODUCTION

Forage sorghum and Sudan grass play an important role in tackling the issue of quality voluminous fodder deficit, and introducing a larger number of forage crops into production within the system of green forage conveyor (GLAMOCLIJA *et al*., 2010). Since contemporary programs of breeding forage sorghum and Sudan grass are aimed at developing $F_1$ hybrids with pronounced potential for high, quality and stable yields of green biomass, convenient for fresh biomass, hay or silage utilization (PATAKI *et al*., 2006)**,** study of combining abilities of potential parents is exceptionally important in achieving this goal (MIHAJLOVIĆ *et al*., 2007).

Understanding relations among morphologic traits is very important in plant breeding, i.e. their interdependence (correlation coefficients) so as to determine the breeding criteria and possible breeding response of cultivars to certain important traits (IKANOVIĆ *et al*., 2010). Therefore, the issue arises whether it is possible to breed for individual polygenetically-controlled traits. In most cases, there might be unwanted changes to values and other agronomically important traits due to mutual correlations (ŠURLAN–MOMIROVIĆ *et al*., 2005).

Direct breeding for dry matter yield, agronomically most important trait nowadays, in species which have long been domesticated, does not always yield satisfactory results, regardless of the use of contemporary methods. Therefore, it is very important to better understand morphological and physiological bases of yield, which would provide efficiency to the breeding process itself (SOKOLOVIĆ, 2006).

Correlations express the level of dependence among traits, and out of numerous correlation coefficients it is often difficult to determine the actual mutual effects among traits. Path analysis provides better study of the nature of such interdependence, while path coefficients serve as an effective parameter for the impact analysis of traits which have an important effect in forming the given correlations. This method enables more quality and full insight into relations existing

among the studied traits, more precise establishment of cause-effect connections among them, as well as to separate direct from indirect effects of any particular trait on dependent variable, being yield in this case. Division of correlations to direct and indirect effects gives a clearer view of traits which can be seen as a backbone of breeding sorghum, as a criterion for successful choice of favourable genetic material.

IKANOVIĆ (2010) concluded that even if correlation values are similar for certain pairs of traits, direct effects for some of them, and especially indirect effects via other traits, can differ for some traits. This is why path analysis is necessary for better understanding of correlations among traits, which is a pathway for knowledge on specificity of the genetic material being studied.

## MATERIALS AND METHODS

Three-year (2007-2009) research was carried out at experimental field Radmilovac. Field micro-trials were set up as randomized block design in 10 replications on basic plot size 10 $m^2$ (5 m x 2 m). Three cultivars developed by Institute of Field and Vegetable Crops in Novi Sad were analysed: forage sorghum c. *Džin* developed in 1983, Sudan grass c. *Zora* developed in 1983, and interspecies hybrid c. *Siloking* developed in 2007.

Standard sorghum cultivation practices were applied. The first cutting was performed in the beginning of tasseling (second ten-day period of July). Samples were taken from freshly cut biomass to analyse morphologic traits (plant height, stem weight, leaf weight and leaf portion in total biomass). Fresh biomass yield was determined by measuring cut aboveground weight from each basic lot and calculating this value per hectare.

During the three research years, there were profound variations in precipitation quantity and distribution. Precipitation amounts for period May-September in the first and second years were below long-term average, while water regime was significantly more favourable in the third year, regarding both quantity and distribution of precipitation (Figure 1).

Heat conditions during sorghum growing period were uniform throughout years, as well as mean values for the area of Radmilovac experimental field.

Weather conditions variations throughout years had no significant effect on growth and development of sorghum, due to which the analysed morphological traits and first cut biomass yield differed slightly throughout the research years.

The experimental data were processed by employing analytical statistics using software STATISTICA 8 for Windows (StatSoft). Coefficients of phenotypic correlations were calculated by analysing covariance of the analysed traits of the studied sorghum cultivars. Indicators of interdependence among analysed traits were gained from relations of joint variations and products of individual variations. Multiple regression path analysis was applied to determine direct effects of efficiency parameters of the analysed morphological traits (independent variable) on green biomass yield (dependent variable), as well as indirect effect via other independent variables, standard errors of path coefficients and testing their significance (WRIGHT, 1934; MALETIĆ, 2005). Standardized regression coefficients,

i.e. path coefficients (WRIGHT, 1934) were calculated by applying the method of the inverse symmetric correlation matrices proposed by EDWARDS (1979).

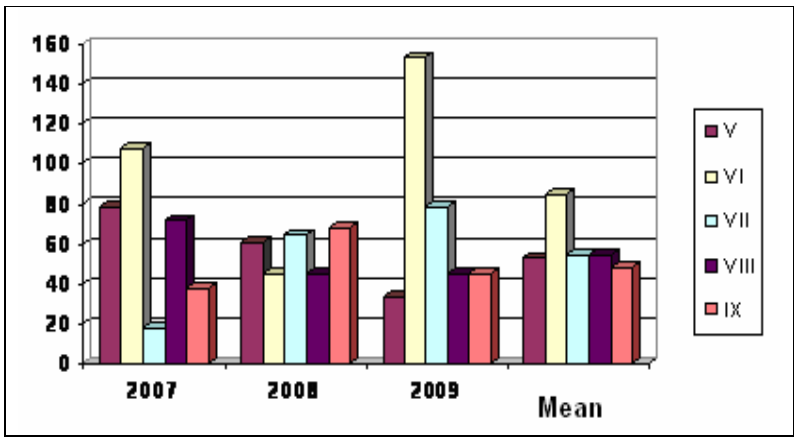


Figure 1. Monthly precipitation for sorghum growing period, mm (Belgrade-Radmilovac)

## RESULTS AND DISCUSSION

In the three-year mean values, Sudan grass c. *Zora* had the highest stem, and forage sorghum c. *NS Džin* had the lowest stem. Stem height variations in the analysed species expressed large statistical differences ($p<0.01$), as shown in Table 1.

At cutting time, forage sorghum had the least leaves on stem (average 7.258), which is significantly ($p<0.05$) less than other two species. Average leaf number of Sudan grass and interspecies hybrid had no significant ($p>0.05$) differences.

Sudan grass stems had the largest amount of developed leaves, but these had the lowest weight (18.291 g), while leaf weight of forage sorghum was 2.7 times larger. Average leaf weight per plant differed significantly ($p<0.05$) among species.

Cultivar *Siloking*, which is an interspecies hybrid between forage sorghum and Sudan grass, had the highest stem weight (100.798 g), which is significant ($p<0.01$) in relation to the parent species. Cultivar *Zora* had the lowest average stem weight (32.545 g), which is significantly ($p<0.01$) less than other two species.

Leaves are of higher nutritive value than stems, so that biomass quality largely depends on leaf portion in the total yield. Forage sorghum had the largest leaf portion (63.2%) in total aboveground biomass (Table 2).

*Table 1 Statistical significance of the differences among morphological traits in sorghum cultivars*

| Species, Cultivar | Stem length, m | Leaf number | Leaf mass, g | Stem mass, g |
|---|---|---|---|---|
| | $\bar{x} \pm S\bar{x}$ | | | |
| *NS Džin* | $1.674^{c} \pm 0.036$ | $7.258^{b} \pm 0.148$ | $49.053^{a} \pm 4.565$ | $77.617^{b} \pm 2.642$ |
| *Zora* | $2.281^{a} \pm 0.039$ | $7.917^{a} \pm 0.124$ | $18.291^{c} \pm 0.278$ | $32.545^{c} \pm 0.638$ |
| *Siloking* | $1.840^{b} \pm 0.029$ | $7.692^{a} \pm 0.099$ | $39.531^{b} \pm 0.969$ | $100.798^{a} \pm 1.639$ |
| LSD 0.05 | 0.071 | 0.268 | 7.330 | 4.234 |
| LSD 0.01 | 0.094 | 0.354 | 9.661 | 5.581 |

a, b, c –Values with different letter in superscript are significantly different ($p<0.05$)

*Table 2 Statistical significance of the differences between productive traits in sorghum cultivars*

| Species, Cultivar | Portion of leaves, % | Fresh biomass yield, t ha$^{-1}$ |
|---|---|---|
| | $\bar{x} \pm S\bar{x}$ | |
| *NS Džin* | $63.2^{c} \pm 0.036$ | $59.31^{b} \pm 0.734$ |
| *Zora* | $56.2^{a} \pm 0.039$ | $53.83^{a} \pm 0.896$ |
| *Siloking* | $48.9^{b} \pm 0.029$ | $58.46^{c} \pm 1.399$ |
| LSD 0.05 | 0.93 | 0.986 |
| LSD 0.01 | 1.26 | 1.340 |

a, b, c –Values with different letter in superscript are significantly different ($p<0.05$)

Interspecies hybrid had the lowest leaf portion in total yield, less than 50%. There were significant ($p<0.01$) variations among species.

Fresh biomass yield in the first cutting was above 50 t ha$^{-1}$ which showed that cultivars of these species feature intensive spring growth and high genetic yield potential. Cultivar *Zora* had the lowest yield and forage sorghum had the highest yield, while variations among cultivars were significant only in relation to Sudan grass.

MALETIĆ *et al*. (2010) highlight the especially important position of phenotypic correlations which point to trends of possible changes under the influence of breeding methods applied.

Therefore, correlation relations among 6 morphologic and productive traits of the analysed *Sorghum* cultivars were tested on the studied samples. Statistically significant and very significant differences were found between individual traits, expressed by phenotypic correlation coefficients (Table 3).

Statistical significance of phenotypic correlation coefficients, gained for some morphologic traits and their effect on green biomass yield, is considered to be of great importance for developing new cultivars within a species, but also for developing interspecies hybrids. Direct breeding for agronomically most important traits does not always yield satisfactory results, regardless of contemporary methods being used. Consequently, it is very important to understand the functional

morphologic or physiologic connections between traits, i.e. in which way and to what extent any individual trait affects another, and *vice versa*. This is confirmed by the results of ŠURLAN-MOMIROVIĆ *et al*. (2005), who conclude that when breeding for certain traits controlled by a larger number of genes, there are often trends of unwanted changes in other important traits due to mutual correlative relations of traits conditioned by genetic linkage, or pleiotropy.

*Table 3 Phenotypic correlation coefficients for morphological and productive traits of sorghum, Sudan grass and interspecies hybrid*

| Traits | Plant height | Leaf number | Leaf weight | Stem weight | Leaf portion | Green biomass yield |
|---|---|---|---|---|---|---|
| Plant height | | 0.21 | -0.80 | -0.59 | 0.49 | -0.33 |
| Leaf number | 0.18 | | 0.46 | 0.71 | -0.81 | 0.93** |
| Leaf weight | -0.8 | 0.44 | | 0.96** | 0.94** | 0.83 |
| Stem weight | -0.59 | 0.69 | 0.95** | | -0.99** | 0.96** |
| Leaf portion | 0.47 | -0.78 | 0.90* | -0.98** | | -0.99** |
| Green biomass yield | -0.33 | 0.87* | 0.83 | 0.95** | -0.98** | |

Simple correlation coefficients show the existence of very strong to almost complete statistically very significant positive relations, and these effects were expected. Plant height and leaf number were not directly significantly correlated with green biomass yield.

The analysis of simple correlations showed that correlation coefficients between plant height and green biomass yield on the one side, and plant height and leaf number on the other side were very unstable and varied from insignificant and very weak to sporadically moderate and statistically significant (Table 4).

Path analysis of the influence of phenotypic coefficients on green biomass yield showed that stem weight had a very strong direct statistically very significant positive effect green biomass yield (2.775**), while leaf weight had negative effect (-1.891**). Plant height had a significant positive effect (0.243*), and leaf number had negative effect (-0.249*). Other variations were below the level of significance 0.05 (*).

Previous studies on interdependence and direct and indirect effects of different morphologic and technologic traits of plant species often show deviations between results gained by simple correlation and path analysis (ŠURLAN-MOMIROVIĆ, 2005; SOKOLOVIĆ *et al*., 2011). In case of economically most important trait - green biomass yield, this means that its expression is conditioned by very complex system

of different physiologic and morphologic indices. TAYLOR (2004) points out that parsing and analysing individual morphologic traits from different aspects is necessary to define reliable strategy in plant breeding and to achieve expected results in yield potential increase in new cultivars. Genotype has a significant impact on properties and other field crops (POPOVIĆ *et al*.. 2011).

*Table 4 Path coefficients for green biomass yield (direct effect / indirect effect)*

| Phenotypic correlation coefficients | | | | |
|---|---|---|---|---|
| Traits | Height | Leaf number | Leaf weight | Stem weight |
| Height | 0.243* | 0.036 | 0.194 | 0.143 |
| Leaf number | -0.037 | -0.249* | -0.110 | -0.172 |
| Leaf weight | -1.513 | -0.832 | -1.891** | -1.796 |
| Stem weight | 1.637 | 1.915 | 2.636 | 2.775** |
| Total | -0.33 | 0.87 | 0.83 | 0.95 |
| Determination coefficient $R^2_{y.1234}$ | | | 92.96% | |

Significant at 0.05 (*) and 0.01 (**), ns – not significant

The effects of the studied morphologic traits on green biomass yield in these cultivars and their complex mode of action in forming total yield can be a significant backbone of further sorghum breeding (Figure 2).

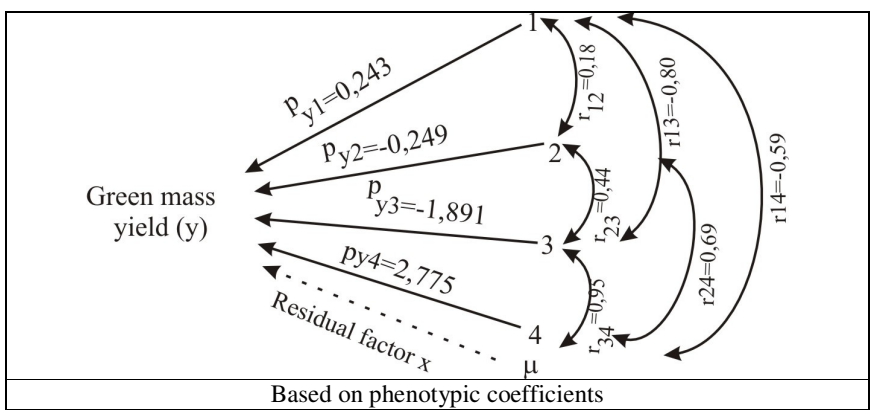


Figure 2 Path diagram and coefficients of the variables which affect green biomass yield of forage sorghum, Sudan grass and interspecies hybrid

Generally, there are significant deviations between phenotypic correlation coefficients relative to direct and indirect effects of the same parameters, which confirm exceptional divergence and heterogeneity of the analysed material.

## CONCLUSIONS

The research results of phenotypic correlation coefficients for productive traits of three *Sorghum* species showed the following:

Morphologic traits - stem height and weight significantly affected sorghum green biomass yield. Leaf number and leaf portion in total biomass were negatively correlated with yield. Cultivars differed significantly regarding morphologic and productive traits. Sudan grass had the lowest green biomass yield, while forage sorghum and interspecies hybrid had significant yield increase.

Significant deviations between phenotypic coefficients in direct and indirect impact of the traits on dependent variable were confirmed by path analysis, which showed exceptional divergence and heterogeneity in the analysed material.

Therefore, the results gained by path analysis are in concordance with the results gained by analysing their interdependence. Despite these, leaf weight and stem weight had direct and highly significant effect on green biomass yield in all three research years.

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# PATH ANALIZA PRODUKTIVNIH OSOBINA VRSTA RODA *SORGHUM*

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I z v o d

Predmet istraživanja ove studije su fenotipski koeficijenti korelacije tri vrste roda *Sorghum*, i to krmni sirak *S. bicolor* Moench. (genotip *NS-Džin*), sudanska trava *S. sudanense* L. (genotip *Zora*) i interspecies hibrid *S. bicolor* x *S. sudanense* (genotip *Siloking*). Analize su urađene na uzorcima biljnog materijala iz prvog otkosa kada su biljke bile u početku faze metličenja. Proučavane su sledeće morfološke osobine: visina biljke, broj listova po biljci, masa listova na stablu i prosečna masa stabla i analiziran je njihov direktan i indirektan uticaj na zavisno promenljivu prinos zelene biomase za koju su izračunati path koeficijenti. Ovom metodom moguće je kvalitetnije i potpunije sagledati odnose koji postoje između proučavanih osobina, preciznije ustanoviti uzročno-posledične veze između njih i razdvojiti direktne i indirektne efekte jedne osobine na zavisno promenjivu osobinu, u ovom slučaju prinos biomase. Analizom fenotipskih koeficijenata uočavaju se razlike u direktnom i indirektnom delovanju nekih pokazatelja na zavisno promenljivu. Najveću vrednost visine stabla imala je sudanska trava (2.281 m), kao i broj listova po biljci (7.917). Najveća masa listova po biljci bila je u krmnog sirka (49.05 g), a najveću prosečnu masu stabla imale su biljke interspecies hibrida (80.798 g). Variranja ovih morfoloških pokazatelja po vrstama bila su signifikantna i vrlo signifikantna.

Morfološke osobine, visina i masa stabla značajno su uticali na prinos zelene biomase sirkova. Broj listova, kao i njihov udeo u ukupnoj biomasi ispoljio je negativan uticaj na prinos. Genotipovi su se po morfološkim i proizvodnim osobinama značajno razlikovali. Najmanji prinos zelene biomase imala je sudanska trava. Značajno povećanje prinosa bilo je u genotipova krmnog sirka i interspecijes hibrida.

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