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*Full Length Research Paper*

# Productivity of *Acacia angustissima* accessions at two sites in the subtropics

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**Low leaf biomass yields coupled with small land sizes are some of the major constraints faced by smallholder farmers that grow protein-rich fodder trees and shrubs. Given these challenges, availability of highly productive seed sources would be important to enable farmers to produce leaf fodder in sufficient quantities. 14 accessions of *Acacia angustissima* were evaluated for leaf, wood and total biomass production at two subtropical sites with uni-modal rainfall in Zimbabwe, with the objective of identifying high leaf biomass yielding accessions. There were up to fourfold difference in biomass yield between the accessions. Leaf dry matter yield ranged from 1.65 to 8.81 Mg ha$^{-1}$ and 3.7 to 12.4 Mg ha$^{-1}$ for wood biomass at the higher altitude site (1530 m a.s.l.) but were much lower at 1272 m a.s.l. where they ranged between 0.37 and 4.88 Mg ha$^{-1}$ for leaf and 0.4 and 7.2 Mg ha$^{-1}$ for wood. The most productive accessions for leaf biomass were 16231 and 18579 at the higher altitude site, while 18586 and 18501 had the highest yields at the lower altitude. Although no one accession was consistently high yielding across the two sites, the least productive accessions were consistently poor at both sites. The advantage of using selected superior accessions over the unselect bulk seed was up to 85%. These findings underscore the need to promote the use of only high yielding accessions rather than unselect bulk seed. This study identified new, more productive accessions of *A. angustissima* that potentially widens the genetic base of the germplasm assembled in Zimbabwe.**

**Key words:** Leaf biomass, accession, accession × site interaction, *Acacia angustissima*.

## INTRODUCTION

Highly productive species and seed sources for fodder production are required by smallholder livestock farmers who are constrained by small land sizes to produce fodder in sufficient quantities for their livestock and other needs in the subtropics. In the early years of the promotion of fodder shrub species, *Leucaena leucocephala* was the species of choice in southern Africa and elsewhere, up until the time the species succumbed to the devastating psyllid attack (Odenyo et al., 2003). This, coupled with poor yields of the species, heightened the need to identify and promote a wider range of fodder tree species together with diverse seed sources, as the susceptible leucaena was believed to have been introduced from a restricted source. The protein-rich species that have been evaluated include a range of *Leucaena* spp., *Gliricidia sepium*, *Calliandra calothyrsus* and *Acacia angustissima* (Odenyo et al., 2003) and African *Acacias* (Barnes et al., 1999).

*A. angustissima* (Miller) Kuntze [syn. *Acaciella angustissima* (Miller) Britton and Rose; *Mimosa angustissima* Miller; *M. ptericina* Poir.; *Senegalia angustissima* (Miller) Pedley] is a leguminous small tree or shrub that is native to the Americas (McVaugh, 1987;

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Rico Arce and Bachman, 2006). Its range of distribution stretches from southern United States, through Mexico and Central America to Venezuela, Colombia, Peru, Ecuador, Bolivia and Northern Argentina (Rico Arce and Bachman, 2006; Csurhes and Navie, 2009). Its altitude of occurrence is between 0 to 2600 m above sea level and rainfall of between 895 and 2870 mm per annum (McVaugh, 1987). It is a fast-growing small tree that is adapted to a wide range of soils; free draining, acidic and infertile soils, and shows excellent drought tolerance, retaining its green leaves during long dry season (Gutteridge, 1994).

*A. angustissima* displays a high degree of morphological variability over its natural range, and consists of several distinct varieties that have caused considerable confusion over its identity (Csurhes and Navie, 2009). A recent taxonomic review by Rico Arce and Bachman (2006) proposed transferring this species to the reinstated genus, *Acaciella*, after the division of the *Acacia* genus into several genera. Under the new genus, the species has three recognised varieties namely *Acaciella angustissima* var. *angustissima, A. angustissima* var. *filicioides and A. angustissima* var. *texensis* (Rico Arce and Bachman, 2006). *A. angustissima* var. *angustissima* is the fastest growing and most widely distributed species of this genus (Rico Arce and Bachman, 2006).

In this paper, the species will be referred to as *Acacia angustissima*, rather than the recent name (*Acaciella angustissima*), as this change has yet to become widely accepted. *A. angustissima,* together with the other tropical leguminous trees and shrubs have been a subject of intense germplasm exploration and evaluation with a view to identify superior seed sources for use as livestock fodder (Hove et al., 1999), soil fertility improvement (Sileshi and Mafongoya, 2007), and wood production (Nyadzi et al., 2003) in smallholder farming systems. The species grows rapidly and responds well to regular cutting. The species has also been shown to respond well to coppicing. Frequent cutting typically occurs in the cut-and-carry fodder system of the smallholder farming system. The leaves of *A. angustissima* have high nitrogen content, which make them an ideal supplement to the low quality crop residues and other grasses that make up the bulk of livestock diets in smallholder livestock sector of southern Africa. Besides fodder, the species is also used for fuel wood, building materials, wind breaks, reclamation of degraded lands and erosion control.

Biomass production on a dry matter basis in *A. angustissima* reported in studies conducted to date, range between 10.3 and 12.4 Mg ha$^{-1}$, depending on age, spacing, site quality and frequency of harvesting (Dzowela et al., 1997). In Zimbabwe, *A. angustissima* has been shown to outperform *Calliandra calothyrsus*, *Gliricidia sepium* and *Sesbania sesban* (Dzowela et al., 1997). Bray et al. (1997) also concluded that *A. angustissima* produced significantly more leaf biomass than other leguminous shrubs at sites in Indonesia and Australia. Under smallholder farming conditions, Matimati et al. (2009) found leaf biomass yields ranging from 0.4 to 3.3 Mg ha$^{-1}$ for *A. angustissima*.

Although a number of trials have been conducted comparing *A. angustissima* and other leguminous fodder trees, testing of accessions of this species has however been limited. In the few evaluation trials conducted, Hove et al. (1999) evaluated five accessions and found leaf dry matter yield of between 5.66 and 10.4 Mg ha$^{-1}$, based on four-year old trees. The present study was conducted with the objective of ascertaining whether the conclusions and recommendations resulting from the earlier evaluation based on fewer accessions are valid, and to examine if the inclusion of a number of additional accessions not tested in the earlier tests would substantially modify the conclusions. The accessions included in this series of tests represent a significant sample of germplasm of *A. angustissima* from its natural range of distribution.

## MATERIALS AND METHODS

The 14 accessions of *A. angustissima* used in the study were supplied by the International Livestock Research Institute (ILRI) (Table 1). Information on the exact location of collection and country of origin of at least three accessions could not be established by the germplasm supplier. Based on the fact that the locality of some of the germplasm could not be ascertained, reference to each of the seedlots was mostly on the basis of the ILRI accession numbers rather than the standard practice in forestry of using the provenance name that is, locality name where the germplasm was collected. The other reference codes for other institutions were also retained for future reference by other users as well (Table 1).

The seeds were sown in polythene tubes at Domboshawa Training Centre (DTC), in September 2000 and the seedlings were used to establish two evaluation trials, one at DTC and the other at Henderson Research Station (HRS) in November of the same year. The DTC (altitude 1,530 m a.s.l., latitude 17° 35' S and longitude 31° 10' E) receives an average rainfall of about 895 mm per year which falls in the summer season (November to April). The average annual temperature is 18.8°C, with the highest and lowest monthly mean temperatures being 29°C (October) and 6.5°C (July), respectively. The soil is coarse sandy loams (classified as Haplic Lixisol) derived from granitic parent material with relatively low water holding capacity. Henderson Research Station (altitude 1,272 m a.s.l., latitude 17° 35' S, longitude 30° 58' E) receives a mean annual rainfall of 880 mm, with a monthly minimum and maximum temperatures ranging from 3 to 16°C and 23 to 30°C, respectively. Effective rainfall is also received during the summer months of November through to April. The soil is medium-grained sandy clay classified as ‘fersiallitic’. The climate of DTC and HRS is characterised by warm conditions during the growing season and by a dry season which is relatively cool from May to August (when ground frosts are not uncommon) and hot from September to November.

A randomised complete block design was used with three replications. Individual accessions were randomly assigned to one of the plots in each replication. The plot was a 4 × 6 that is, 24 trees spaced at 1.0 m between rows and 0.5 m within rows. There were

**Table 1.** Geographic locations of the accessions used in the study.

| Accession number (ILRI[1]) | Other reference code | Provenance name | Country of origin | Altitude (m a.s.l.) | Latitude N | Longitude E |
|---|---|---|---|---|---|---|
| 18578 | [2]OFI 70/93 | Volcan Salvador | El Salvador | 1190 | 13° 72' | 89° 27' |
| 16261 | OFI 37/88 | Guatemala City | Guatemala | na | 14° 62' | 90° 53' |
| 18582 | [3]CPI 84998 | Baja California | Mexico | 100 | 22° 92' | 109° 92' |
| 18575 | OFI 66/92 | Tuxtepec | Mexico | 20 | 18° 17' | 95° 92' |
| 469 | CF 875 | San Jose | Belize | 7 | 18° 17' | 88° 50' |
| 459 | [4]CIAT 9439; CPI 75981 | Escarega | Mexico | 45 | 18° 82' | 90° 67' |
| 16501 | OFI 38/88 | Cerro Uyuca | Honduras | na | 15° 50' | 86° 47' |
| 18574 | OFI 65/92 | San Marcos | Guatemala | 2000 | 14° 90' | 91° 77' |
| 15132 | [5]NFTA 472 | Puriscal | Costa Rica | 1100 | 09° 83' | 84° 30' |
| 460 | CIAT 9455; CPI 75982 | Chencoyi | Mexico | 50 | 19° 70' | 90° 49' |
| 18577 | OFI 68/92 | Putla de Guerrero | Mexico | 950 | 17° 15' | 97° 87' |
| 18580 | CPI 51615 | Unknown | Unknown | Unknown | Unknown | Unknown |
| 18579 | CPI 21488 | Unknown | Unknown | Unknown | Unknown | Unknown |
| 18586 | CPI 21488 | Unknown | Unknown | Unknown | Unknown | Unknown |

[1]International Livestock Research Institute, [2]Oxford Forestry Institute (of UK), [3]CPI Commonwealth Plant Introduction (of Australia), [4]International Centre for Tropical Agriculture (CIAT), [5]Nitrogen Fixing Trees Association.

enough seedlings to establish all the 14 accessions at Domboshawa and 11 accessions at Henderson. The trials were weeded as necessary. The trials were assessed for survival and biomass production (leaves, wood and pods) at 30 months after planting by cutting the trees back to 30 cm above ground. Only trees in the net plot of 2 × 4 that is, eight trees were assessed. The biomass was separated into leaves, pods and wood. Each of the biomass components were weighed fresh and 200 g sub-samples were collected and oven-dried at 70°C for 48 h to constant weight, to determine the dry weights. From the subsamples, dry weights of each of biomass components for each plot were determined. The total biomass was derived as a sum of all the three components (leaf, pod and wood).

### Data analysis

There were no missing plots so the data was balanced. The analyses of variance for all the biomass traits were based on plot means. Single site analyses were conducted for each of the two tests to derive accession means. The PROC GLM (SAS, 1998) was used to analyse the data, to test the significance of the accession effect and to derive accession least squares means. The linear model fitted to test the significance of the treatments (accession) effects was:

$$Y_{ij} = \mu + R_i + A_j + \varepsilon_{ij}$$

Where, $Y_{ij}$ = observation in the ij$^{th}$ plot, $\mu$ = trial mean, $R_i$ = fixed effect of the i$^{th}$ replication, $A_j$ = fixed effect of the j$^{th}$ accession, $\varepsilon_{ij}$ = experimental error, $E[\varepsilon_{ij}] = 0$, $\text{Var}[\varepsilon_{ij}] = \sigma^2_\varepsilon$.

Significant differences among the accession means were determined and separated using the Duncan multiple range test for individual sites.

### Accession effects

Accession effects ($AE_i$) were estimated for leaf, wood and total biomass yield as a deviation of the accession least squares mean ($X_i$) from the mean of all the accessions that is, the site mean ($X.$) divided by the site mean as a percentage.

$$AE_i = \frac{X_i - X.}{X.} * 100$$

The expression indicates the potential gain in yield that would be realized from using germplasm of any of the individual accessions instead of bulk seed of all accessions. The accession effect is a relative measure which depends on the other accessions included in the test and the site.

### Accession × site interaction

For the across site analysis, only 11 accessions that were common to both sites were retained for the data analysis. The across site analysis was conducted to test the significance of the accession × site interaction for the biomass traits. An across site analysis with more sites would have been more powerful and insightful than one involving only two sites. To remove the bias of the accession × site interaction variances as a result of heterogeneous variances (scale effects), individual plot observations of each site were first standardized by dividing the observations with the individual site standard deviation. The linear model used was:

$$Y_{ijk} = \mu + S_i + R(S)_{ij} + A_k + SA_{ik} + \varepsilon_{ijk}$$

Where, $y_{ijk}$ = observation of the ijk$^{th}$ plot, $\mu$ = across site mean, $S_i$ = fixed effect of the i$^{th}$ site, $R(S)_{ij}$ = fixed effect of the j$^{th}$ replication in the i$^{th}$ site, $P_k$ = fixed effect of the k$^{th}$ accession, $SP_{ik}$ = fixed effect of interaction between the i$^{th}$ site and k$^{th}$ accession and $\varepsilon_{ijk}$ = experimental error, $E[\varepsilon_{ijk}] = 0$, $\text{Var}[\varepsilon_{ijk}] = \sigma^2_\varepsilon$.

## RESULTS

### Survival and biomass production

Tree survival was above 80% at Domboshawa while

**Table 2.** Variance ratios (F-values) for individual site analysis of variance.

| Source of Variation | DF | Domboshawa | | | Henderson | | |
|---|---|---|---|---|---|---|---|
| | | leaf | wood | Total biomass | leaf | Wood | Total biomass |
| Replication | 2 | $0.23^{ns}$ | $1.05^{ns}$ | $0.80^{ns}$ | $3.12^{ns}$ | $2.61^{ns}$ | 5.95** |
| Accession | $13^{\#}$ | 7.35*** | 2.72* | 3.32** | 4.66** | 7.47*** | 5.18*** |
| Error | $26^{\S}$ | | | | | | |

$^{\#}$DF, 10 and $^{\S}$DF, 20 at Henderson; ns, not significant at 5%; *, ** and ***, significant at 5, 1 and 0.1%, respectively.

**Table 3.** Accession means of dry matter leaf, wood and total biomass yield (Mg $ha^{-1}$) at Domboshawa.

| Accession | Leaf biomass (Mg $ha^{-1}$) | Rank | Wood biomass (Mg $ha^{-1}$) | Rank | Total biomass (Mg $ha^{-1}$) | Rank |
|---|---|---|---|---|---|---|
| 16261 | $8.81^{a}$ | 1 | $9.19^{abcd}$ | 6 | $18.25^{a}$ | 2 |
| 18579 | $7.57^{ab}$ | 2 | $12.37^{a}$ | 1 | $19.94^{a}$ | 1 |
| 16501 | $7.14^{abc}$ | 3 | $10.21^{abc}$ | 4 | $17.78^{ab}$ | 4 |
| 18578 | $6.60^{abcd}$ | 4 | $8.45^{abcd}$ | 7 | $15.05^{abcd}$ | 7 |
| 15132 | $6.19^{bcde}$ | 5 | $11.90^{a}$ | 2 | $18.09^{ab}$ | 3 |
| 18574 | $5.56^{bcdef}$ | 6 | $9.50^{abcd}$ | 5 | $15.16^{abcd}$ | 6 |
| 18586 | $4.49^{defg}$ | 7 | $11.17^{ab}$ | 3 | $17.01^{ab}$ | 5 |
| 18575 | $4.26^{defgh}$ | 8 | $7.95^{abcd}$ | 8 | $12.90^{abcd}$ | 8 |
| 18577 | $3.68^{efgh}$ | 9 | $7.69^{abcd}$ | 9 | $11.93^{abcd}$ | 9 |
| 18582 | $3.53^{fgh}$ | 10 | $5.44^{bcd}$ | 10 | $9.42^{bcd}$ | 10 |
| 18580 | $2.88^{gh}$ | 11 | $4.26^{cd}$ | 12 | $7.53^{cd}$ | 11 |
| 469 | $2.22^{gh}$ | 12 | $4.03^{cd}$ | 13 | $6.67^{d}$ | 14 |
| 459 | $2.18^{gh}$ | 13 | $3.70^{d}$ | 14 | $7.05^{d}$ | 13 |
| 460 | $1.65^{h}$ | 14 | $4.54^{cd}$ | 11 | $7.40^{d}$ | 12 |
| Mean | 4.76 | | 7.67 | | 12.91 | |

Means followed by a common letter do no differ significantly at 5% based on Duncan multiple range test.

survival at Henderson ranged between 41.7 and 95.8%, with four accessions having survival below 80%. The accession effect for the leaf, wood and total biomass yield was significant at different probability levels at both sites (Table 2). The leaf, wood and total biomass dry matter production at Domboshawa ranged between 1.65 and 8.81 Mg $ha^{-1}$, 3.70 and 12.37 Mg $ha^{-1}$ and between 6.67 and 19.94 Mg $ha^{-1}$, respectively (Table 3). In terms of leaf biomass, the most important trait for fodder and green manure production, the most productive accessions were 16261, 18579, 16501 and 18578. Pod yields were up to 1.35 Mg $ha^{-1}$, although three accessions (15132, 18578 and 18579) did not produce any pods (data not shown).

The biomass yields at Henderson ranged from 0.37 to 4.88 Mg $ha^{-1}$ for leaf, 0.43 to 7.18 Mg $ha^{-1}$ for wood and 0.91 to13.52 Mg $ha^{-1}$ for total biomass and were substantially lower than those at Domboshawa (Table 4). The most productive accessions for leaf biomass were 18586, 16501, 18577 and 16261. Pod production was up to 1.45 Mg $ha^{-1}$, but two accessions (15577 and 18578) did not produce any pods (data not shown). Between the two sites, only one accession (18578) consistently failed to produce pods, while the accession 18586 produced the highest pod yields at the two sites.

## Accession effects

The accession effects illustrate the potential gain that would be realised from using seed of individual accessions instead of bulk seed of all the accessions for operational planting as is often the case in systems that do not recognise seed quality. The accession effect is a relative measure which depends on the performance of other accessions included in the test and the site. The accession effects for leaf biomass ranged from -65 to 85% at Domboshawa, and from -87 to 73% at Henderson (Figure 1a). Of the 11 accessions common to the two sites, only three (16261, 16501 and 18578) had consistently positive effects, while a further four had consistently negative effects, and the remainder (four) had both positive and negative effects at the two sites.

The accession effects for wood dry matter yield ranged between -52 and 61% at Domboshawa and between -89 and 88% at Henderson (Figure 1b). Six of the 11

**Table 4.** Accession means for dry matter leaf, wood and total biomass (Mg ha$^{-1}$) at Henderson.

| Accession | Leaf biomass (Mg ha$^{-1}$) | Rank | Wood biomass (Mg ha$^{-1}$) | Rank | Total biomass (Mg ha$^{-1}$) | Rank |
|---|---|---|---|---|---|---|
| 18586 | 4.88$^{a}$ | 1 | 7.18$^{a}$ | 1 | 13.52$^{a}$ | 1 |
| 16501 | 4.29$^{ab}$ | 2 | 4.19$^{ab}$ | 6 | 8.55$^{bc}$ | 4 |
| 18577 | 4.13$^{ab}$ | 3 | 5.10$^{ab}$ | 3 | 9.23$^{ab}$ | 3 |
| 16261 | 3.69$^{ab}$ | 4 | 4.29$^{ab}$ | 5 | 8.04$^{bc}$ | 5 |
| 18578 | 3.40$^{abc}$ | 5 | 6.84$^{ab}$ | 2 | 10.23$^{ab}$ | 2 |
| 18574 | 2.47$^{abc}$ | 6 | 2.65$^{bc}$ | 8 | 5.28$^{bcd}$ | 8 |
| 18575 | 2.47$^{abc}$ | 7 | 4.40$^{ab}$ | 4 | 7.04$^{bc}$ | 6 |
| 469 | 2.33$^{abc}$ | 8 | 2.67$^{bc}$ | 7 | 5.48$^{bcd}$ | 7 |
| 15132 | 1.80$^{bc}$ | 9 | 2.07$^{bc}$ | 10 | 3.97$^{cd}$ | 9 |
| 460 | 1.18$^{bc}$ | 10 | 2.20$^{bc}$ | 9 | 3.88$^{cd}$ | 10 |
| 459 | 0.37$^{c}$ | 11 | 0.43$^{c}$ | 11 | 0.91$^{d}$ | 11 |
| mean | 2.82 | | 3.82 | | 6.92 | |

Means followed by a common letter do not differ significantly at 5% based on Duncan multiple range tests.

**Table 5.** Variance ratios (F-values) for combined site analysis for leaf, wood and total biomass.

| Source | DF | Leaf | wood | Total biomass |
|---|---|---|---|---|
| Sites | 1 | 10.44* | 19.41** | 19.61** |
| Replication-within-site | 4 | 1.38$^{ns}$ | 1.96$^{ns}$ | 1.96ns |
| Accessions | 10 | 2.84$^{ns}$ | 2.81$^{ns}$ | 3.27* |
| Site × accession | 10 | 3.74** | 1.73$^{ns}$ | 1.85$^{ns}$ |
| Error | 40 | | | |

ns, Not significant at 5%; *, **, and ***, significant at 5, 1 and 0.1%, respectively.

accessions common to the two sites had consistently positive effects; three had consistently negative effects and two had both negative and positive effects at both sites. The accession effects for total biomass ranged from -45 to 54% at Domboshawa and from -87 to 95% at Henderson (Figure 1c). Of the 11 accessions common to the two sites, four had positive effects; three had negative effects while the remaining four, had both negative and positive effects.

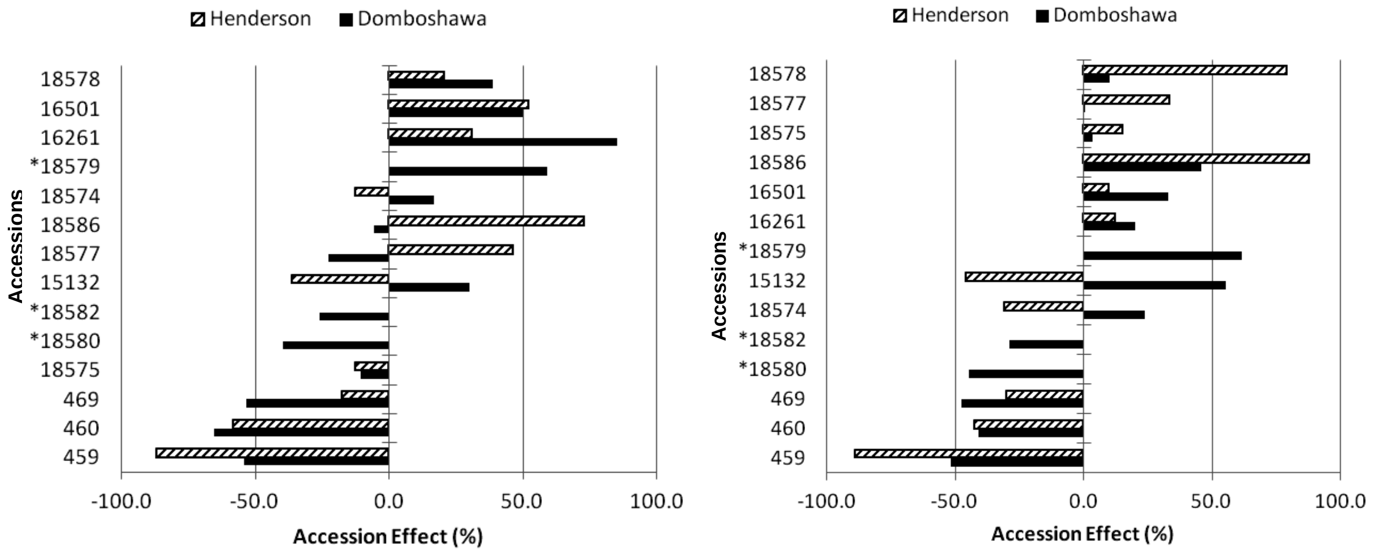
## Site × accession interaction

Across the two sites, the site effect was significant at different probability levels for leaf, wood and total biomass (Table 5). The accession effect was only significant ($P < 0.05$) for total biomass but was non significant for its components: the leaf and wood biomass. The site × accession interaction was significant ($P < 0.01$) for leaf biomass yield but was not significant for wood and total biomass yield (Table 5).

## DISCUSSION

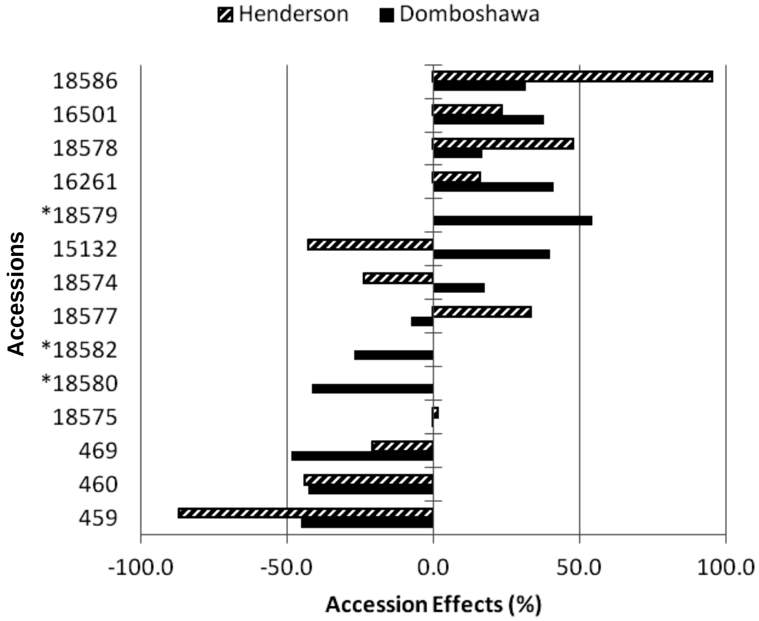
The primary purpose of growing legume trees such as *A. angustissima* by resource poor smallholder farmers in the sub-tropics is for fodder production and soil fertility improvement as green manure. Both systems will be optimised by use of seed sources that have a high leaf biomass yield potential, more so in areas where land availability is a constraint. The 14 accessions of *A. angustissima* assessed in the present study showed a high degree of variability in dry matter leaf, wood and total biomass production. These large differences in productivity could be exploited by using only the highly productive accessions rather than bulking the accessions in operational plantings, as commonly practised in production systems that do not differentiate seed quality beyond seed viability. The selective deployment and use of highly productive accessions would potentially have large implications on smallholder farming systems where availability of land for growing fodder trees is a constraint.

The leaf biomass in the present study showed wide genetic variation among the accessions, with the most productive accession producing five times more leaf biomass yield compared to the least productive accession and twice the species' mean yield potential. The large genetic variation in leaf and wood biomass production among accessions has also been reported in other tropical leguminous shrubs such as *Gliricidia*



(a) Leaf biomass

(b) Wood biomass



(c) Total biomass

**Figure 1.** Accession effects expressed as a percentage above (+) or below (-) site mean leaf, wood and total biomass yield at two sites. *Accession not tested at Henderson.

*sepium* (Cobbina and Atta-Krah, 1992; Ngulube and Mwabumba, 1994) and *Calliandra calothyrsus* (Duguma and Mollet, 1997; McDonald et al., 2000).

Direct comparison of the leaf biomass yields of the present study with those reported in other studies is less precise because the tests were evaluated at different ages. For example, the present study was based on 2½-year growth while that reported by Hove et al. (1999) was based on 4-year growth. In the study by Hove et al. (1999), leaf dry matter yield ranged between 5.6 and 10.4 Mg ha$^{-1}$. The yield range in the present study was even wider, ranging from 1.6 to 8.8 Mg ha$^{-1}$ at the same site. However, a comparison of the ranking of the accessions is, nevertheless possible and more informative. The top ranked accession, 18578 (Volcan Salvador provenance) in the study by Hove et al. (1999), was only ranked 4th at Domboshawa and 5th at Henderson, for leaf biomass in the present study. All the top four ranked accessions in the present study were all new, as they were not tested in Zimbabwe.

The present study therefore identified more productive seed sources of *A. angustissima*, previously untested, on which, Zimbabwe's future fodder production and (genetic improvement) could be based on. Puriscal provenance (accession 15132), which has been cited as a highly productive seed source for leaf biomass yield in Ethiopia (Cook et al., 2005), ranked poorly for leaf biomass at Henderson and was only above average at Domboshawa.

The differences among the accessions in wood biomass production were also very large, with the most productive accession (18579) producing more than three times that of the poorest accession. There are two opportunities of exploiting the high wood biomass from some of the accessions of *A. angustissima*. In areas with fuelwood shortage, the choice and planting of accessions that also produce high wood biomass would significantly improve fuel wood supply. The second opportunity to exploit is that of carbon markets. There is increasing realisation that agroforestry could play an important role in the carbon trade (Nair et al., 2009). Exploitation of both the leaf and wood biomass markets would be feasible, as most of the accessions that ranked high on leaf biomass were also ranked very high for wood production.

Flowering and seed production are also critical for the propagation of *A*. *angustissima*. Pod production was assessed at the two sites, and the top ranked accession for leaf biomass (18578) at Domboshawa consistently failed to produce pods at the two sites. However, the accession 18586 had consistently the highest pod yields at both sites. Although the accession 18586 was supplied as *A. angustissima*, the same accession is listed under *Acacia villosa* on the Svalbard Global Seed Vault gene bank website in Norway (http://www.nordgen.org/sgsv/index.php). It was however not possible to get more details about the accession, particularly the exact locality where the collection was made, as it is also not given on the website. One can only speculate that perhaps, at the time of collection, the trees could have been misidentified as *A*. *angustissima* but when corrections were made years later, the germplasm that had already been distributed for field evaluation was inadvertently missed in the changes. These challenges could in future be minimised through accurate germplasm documentation.

Although this study was based on a limited number of sites, there still appears to be some evidence that the genotype × environment interaction (*gei*) is present in *A. angustissima* for some of the traits and appears to be due to changes in the ranks of the accession between the sites. The rank changes were mostly among the average and the highly productive accessions; while the least productive accessions did not change their ranks across the two sites that is, were consistently poor. There are limited studies on *gei* interaction in *A. angustissima* on which comparisons could be made. The presence of *gei* at accession level in this species implies that the deployment of seed must be carefully done to ensure optimum productivity by matching the accessions to suitable sites. No one accession is suitable for growing on all the sites. There is a need to investigate further the significance of *gei* in *A*. *angustissima*, as the present study was limited in scope by the fewer number of sites.

There is evidence that the current planting of agroforestry trees by smallholder farmers is being done without due regard to the productivity of the seed source (Simons, 1996; Shelton, 2000). The present results indicate that the selective use of seed from the most productive accessions for leaf biomass will for example give yields of 73 and 85%, respectively higher at Henderson and Domboshawa compared to the use of bulked seed. These magnitudes illustrate the importance of prudence in the choice of seed for deployment. Where seed for planting can be obtained by provenance identity, there is a need to dissuade the planting of seed from Escarega (accession 459), Chencoyi (460) and San Jose (469), as they were consistently poor in all the attributes assessed at both sites. Conversely, where seed production and supply is by bulk seedlots, accessions with broader adaptation and productivity such as Guatemala City (accession 16261), Cerro Uyuca (16501) and Volcan Salvador (18578) should be promoted in the mix.

The importance of site selection is also very critical in the planting of *A. angustissima*. In this study, yields at Henderson were almost close to 50% of the yields at Domboshawa. Although both sites are in a relatively wet region, Henderson is much warmer than Domboshawa due to its lower elevation. Based on these limited number of sites, we infer that the ecological niche for *A. angustissima* in Zimbabwe appears to be the highveld area, and its productivity could be lower on warmer sites. There is however a need to conduct more comprehensive trials covering a wider range of environments to improve accession-site matching, and consequently biomass yield.

This study identified new, more productive accessions of *A. angustissima* that potentially widens the genetic base of the germplasm being assembled and tested in Zimbabwe. More on-station and on-farm evaluation trials are required to refine the environmental limits for production of this species in Zimbabwe and the sub-region. There is also a need to further elucidate the nature of genotype × environment interaction to enhance germplasm deployment.

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