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Analysis of the Potential for Using Caucasian Bluestem as a Biofuel Crop in the Southeastern United States

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ABSTRACT

Caucasian bluestem, *Bothriochloa bladhii* (Retz.) S.T. Blake, is an introduced warm-season grass planted for forage production and conservation uses in several areas of the United States. It is highly productive and capable of withstanding physical and environmental stresses. Successful establishment and forage production techniques have been developed for this species, proving that it can be managed in a similar manner as other introduced forage grasses commonly grown in the southeastern United States. Further research would be necessary to determine fuel characteristics and optimum management systems for biofuel production before this species could be considered for this use.

INTRODUCTION

Caucasian bluestem is an introduced warm-season (C_4) grass related to native North American bluestem (*Andropogon* L.) species (Taliaferro, et al., 1972). It was formerly known by the name *B. caucasica* (Trin.) C.E. Hubbard (USDA-NRCS, 1999). Caucasian bluestem is one of a group of grasses generally referred to as Old World (or Asiatic) bluestems, which are of mainly European or Asian origin (Sims and Dewald, 1982). Caucasian bluestem is native to the Caucasian Mountains (De Wet and Harlan, 1966) in the Republic of Georgia (formerly part of the USSR) but all material grown in the United States originated from a single accession or introduction from Tbilisi made in 1929. In addition to Caucasian, other Old World bluestems commonly planted in the United States are cultivars of yellow bluestem [*B. ischaemum* (L.) Keng] and its varieties (Sims and Dewald, 1982), with some other species of *Bothriochloa* Kuntze and *Dichanthium* Willem. used mainly in Texas and the Coastal Plains (Gould, 1978). Plants that were formerly identified as *B. intermedia* (R. Br.) A. Camus are now considered to be included in *B. bladhii* (USDA-NRCS, 1999).

Caucasian bluestem is adapted to a wide range of climatic conditions, is relatively winter hardy, highly drought tolerant, has no major pest problems (Sims and Dewald, 1982), and is adapted to frequent defoliation caused by grazing (Belesky and Fedders, 1995; Christiansen and Svejcar, 1987; Sims and Dewald, 1982; Svejcar and Christiansen, 1987a). For these reasons, it has been widely planted in the southern Great Plains of the United States to improve forage production (Svejcar and Christiansen, 1987b; Taliaferro et al., 1984) and to

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reclaim marginal cropland (Sims and Dewald, 1982). It has also been recommended as a supplement for cool-season grass pastures to increase forage production during the summer months (Anderson and Matches, 1983; Belesky and Fedders, 1995; Faix et al., 1980; Forwood et al., 1988; Gerrish et al., 1987; Jung et al., 1990; Wolf et al., 1996). Caucasian bluestem can also be used as a cover plant for critical area plantings (USDA-NRCS, 1996). Caucasian bluestem can produce a large amount of biomass on a wide variety of soil types (Ahring et al., 1978; Dalrymple, 1991; Stout et al., 1986; Wolf et al., 1996). The productivity and adaptability of Caucasian bluestem indicate that it might have potential as a biofuel crop on marginal cropland.

1. Biological Characteristics

1.1. Plant description

Perennial clump-forming grass, growing 0.6 to 1.2 m (2 to 4 ft) tall. It has very fine stems and is quite leafy and deep-rooted (Ball et al., 1991). The leaves are blue-green in color and the stems have a tinge of purple at the node (USDA-NRCS, 1996). Bor (1960) states that, unlike some other Old World bluestems, this species is not aromatic, however, it has been noted that the foliage has a distinctive sweet odor (USDA-NRCS, 1996). The inflorescence is a terminal panicle (Gould and Shaw, 1983). The lower racemes are shorter than the rachis, whereas they are longer in yellow bluestem. The racemes are not very hairy. The lower lemma of the sessile spikelet is about half the length of the lower glume and the lower glume is not pitted. The spikelets are 3 to 3.5 mm long (Bor, 1960).

1.2. Ecological distribution

There are major ecological differences between *Bothriochloa* species that affect their natural distribution, from restricted habitats to wide-ranging ones. The native distribution of Caucasian bluestem in Europe and Asia is not known (Sims and Dewald, 1982). The USDA-Natural Resources Conservation Service (NRCS) PLANTS database (USDA-NRCS, 1999) lists Caucasian bluestem as being represented in the United States in the following states: New Mexico, Colorado, Texas, Oklahoma, Kansas, Nebraska, Missouri, Louisiana, Florida, and Hawaii. Most of the original work on using Caucasian bluestem for forage production was conducted in Oklahoma (Sims and Dewald, 1982). Other states in which it has been grown include, Illinois (Faix, et al., 1980), Virginia (McKenna et al., 1991; Wolf et al., 1996), West Virginia (Belesky and Fedders, 1995; Stout, et al., 1986), and Pennsylvania (Jung et al., 1985; Jung et al., 1990). It is not reliably winter hardy in New England north of Pennsylvania (USDA-NRCS, 1996). These reports show that Caucasian bluestem has a wide area of potential adaptation in the United States, stretching from the area of its original introduction in the southern Great Plains states, through the southern Midwest, the Southeast, and into southern New England. Ball et al. (1991) states that it is best adapted to the western portion of this region. When other Old World bluestems are considered in addition to Caucasian, the potential area where these species could be grown for biofuel uses might be extended further. 'King Ranch' yellow bluestem (see cultivar description below) has been grown successfully in the blackland prairie area of Mississippi (Glenn, personal communication).

1.3. Mode of reproduction – systematics

Old World bluestems reproduce by facultative apomixis (Sims and Dewald, 1982). Caucasian bluestem is a hybrid derived from the highly variable species *B. intermedia* (which is now no longer separated taxonomically from *B. bladhii*) and *Capillipedium parviflorum* (R. Br.) A. Camus (De Wet and Harlan, 1966). Seeds are enclosed in chaffy glumes. Seed dormancy in Caucasian bluestem has not been reported; however, dormancy in yellow bluestem varieties was influenced by environmental conditions during seed development and by seed maturity at

harvest. Removal of surrounding glumes increased germination of fresh yellow bluestem seed. Heat drying after harvest appeared to degrade germination inhibitors present in the glumes of *B. ischaemum* var. *ischaemum* and *B. intermedia* seeds (Sims and Dewald, 1982). Gametophyte (1n) chromosome count is 20 (Missouri Botanical Garden, 1981) and sporophyte (2n) count = 40 (Bor, 1960).

1.4. Invasiveness

Old World bluestems are generally considered as a secondary successional plant, not climax vegetation. Plants increase under heavy grazing and other disturbances and produce large quantities of seeds (Sims and Dewald, 1982). Because the seedlings are fairly difficult to establish (Moser and Nelson, 1983), it seems unlikely that Caucasian bluestem would be highly invasive. Old World bluestems provide little food or habitat for wildlife and no biological diversity to planting sites (Hodges and Bidwell, 1993).

1.5. Genotypes/cultivars

There are no cultivars of Caucasian bluestem, because it is a single accession. It was released by the USDA-NRCS (then known as the Soil Conservation Service) in 1946 (Ahring et al., 1978). There are commercially available cultivars and tested strains of other Old World bluestems and the most commonly used are listed below. Seeds from several morphologically similar Old World bluestem accessions were bulked or blended before evaluation to limit potential pest problems that could result from genetic similarity of apomictic lines and to improve adaptability to diverse planting sites.

Bothriochloa intermedia var. *indica* – (Sims and Dewald,1982). The PLANTS database (USDA-NRCS, 1999) does not list any varieties of *B. intermedia*. Ahring et al. (1978) refers to these plants as *indica* types and De Wet and Harlan (1966) mention two morphologically distinct races of this species. Because this species is now taxonomically grouped with Caucasian in *B. bladhii*, it logically follows that plant material formerly identified as varieties or strains of *B. intermedia* would now be considered a part of same species as Caucasian as well. Plants belonging to the *intermedia* group are not as drought tolerant or as winter hardy as *ischaemum* types and are better adapted to areas with high humidity. Some will also be pungent and high in aromatic oils (Ahring et al., 1978), which would distinguish them from material formerly identified as Caucasian bluestem that, as stated previously, is not aromatic (Bor, 1960).

B blend – blend of 3 accessions from Pakistan and 3 hybrids of *B. intermedia* X *B. ischaemum*.

H blend – blend of 4 lots of accessions collected in the hills of India and Pakistan.

L blend – blend of 8 accessions from Pakistan with large statures.

LL blend – blend of 4 accessions and 1 hybrid from Pakistan; plants have large statures and late maturity.

T blend – blend of lots from the Tarnab Experiment Station in Pakistan.

Bothriochloa intermedia var. *montana*

I blend – blend of 30 hybrids from India; responsive to irrigation.

J blend – blend of 7 hybrids with A-6573b from Afghanistan.

K blend – blend of 3 accessions from the Kulu Valley, India (Sims and Dewald, 1982).

Bothriochloa ischaemum (L.) Keng var. *ischaemum*

'Ganada' – was released by USDA-Soil Conservation Service (SCS) in 1979 for use mainly in Colorado and New Mexico; seed collected in Tajikistan, Turkestan (USDA-SCS, 1979); good drought tolerance and forage quality (Hodges and Bidwell, 1993).

Plains (M blend) – blend of 30 medium-sized accessions from several countries, collected at mid-level elevations; released in 1972 (Sims and Dewald, 1982); tolerant to a wide range of

soil types and resistant to drought and rust (Ahring et al., 1978); longer grazing season (Hodges and Bidwell, 1993).

S blend – blend of 30 accessions originating from many different countries; plants have a smaller stature (Sims and Dewald, 1982).

'WW-Spar' – released in 1982 by USDA-Agricultural Research Service (ARS) and Oklahoma Agricultural Experiment Station (Sims and Dewald, 1982); originated in Pakistan (Hodges and Bidwell, 1993); one selected accession from the mixture that comprises Plains with greater winter hardiness, earlier green-up, greater drought tolerance, and higher forage production (Sims and Dewald, 1982).

'WW-Iron Master'– released by UDSA-ARS and USDA-NRCS in 1987; plant introduction from Afghanistan (Englert and White, 1998; USDA, ND); highly productive and shows less chlorosis when grown on iron deficient soils (USDA, ND).

'El Kan' – smaller and leafier than Plains (Ahring et al., 1978); tested at the Kansas Agricultural Experiment Station (Sims and Dewald, 1982).

Bothriochloa ischaemum (L.) Keng var. *songarica* (Rupr. ex Fisch. & C.A. Mey.) Celarier & Harlan

'King Ranch' – single accession released by USDA-NRCS from an introduction made from China in 1917 (Sims and Dewald, 1982; Webster and Foster, 1949); not cold hardy (Ahring et al., 1978).

2. Production Practices

2.1. Establishment

2.1. a. Seedbed preparation

Grows best on fertile fine-textured soils (Ahring et al., 1978, Dalrymple et al., 1984; Dalrymple, 1991), of moderate or better drainage (USDA-NRCS, 1996), such as loams and some clays (Ball et al., 1991, Hodges and Bidwell, 1993). Old World bluestems will not tolerate wetland or extremely saline soils. They can be planted on sandy loam soils, but not on extremely sandy soils that lack finer-textured subsoils. Stands planted on a sandy loam may take an extra one to two years to become established (Dalrymple et al., 1984; Dalrymple, 1991). Caucasian bluestem can grow well on shallow, rocky soils. It will also tolerate low pH soils (down to 5.2) (Wolf et al., 1996). Old World bluestems will become chlorotic when grown on soils with a pH above 7.5, with the exception of 'WW Iron Master', which is adapted to higher pH soils (Dalrymple, 1991). Old World bluestems can be planted on a prepared seedbed or planted no-till, with planting on a prepared seedbed being the preferred method on sites where erosion is not a consideration (Dalrymple, 1991; Marietta and Britton, 1989). Seedbed preparation should begin the previous fall to early winter if possible (Dalrymple, 1991), and in some areas planting a winter cover crop may be advisable. Planting a smother crop, such as dwarf pearl millet [*Pennisetum glaucum* (L.) R. Br.] the previous season will help control weed problems (Wolf et al., 1996). A clean firm seedbed is crucial (Ahring et al., 1978, Dalrymple, 1991; Wolf et al., 1996). When no-till planting, vegetation should be grazed closely or chemically controlled before planting using paraquat or glyphosate. Large amounts of plant residue are unacceptable (Dalrymple, 1991; Wolf et al., 1996) because the planter may not cut cleanly through the residue. If residue is dense enough, it can be burned before planting (Wolf et al., 1996). Apply lime according to soil test recommendations and incorporate before planting. Potassium (K) can be applied pre-plant or topdressed when the seedlings begin to establish (Dalrymple, 1991).

2.1. b. Planting date

Planting should be delayed until soil temperatures are fairly high (Ahring et al., 1978; Wolf et al., 1996). Seed germination occurs at 16°C (60°F) (Dalrymple, 1991; Sims and Dewald, 1982).

Germination and seedling development were shown to be slower at a lower temperature (20°C) than at higher temperatures (25 and 30°C) (Hsu et al., 1985). Various planting dates have been used from March to August (Dalrymple, 1991), however, planting early in the season ensures adequate temperatures and moisture (Dalrymple, 1991; Hsu et al., 1985). Planting too early can cause Old World bluestem seed to undergo a transitory cold shock or cold-induced dormancy (Dalrymple, 1991). Early work showed that stands established best when sown between late March and mid-April. Peak seedling emergence was in late June. Plantings made from late April to early June were subjected to intense weed pressure and unfavorable environmental conditions. Later work found that planting in late April to early June provided the appropriate temperatures for germination, with fastest germination and growth from May plantings (Sims and Dewald, 1982). May to June planting is probably the best planting window (Ahring et al., 1978; Ball et al., 1991). Wolf et al. (1996) recommend planting from June 10 to July 10 in Virginia or possibly earlier if potential weed growth will not be too dense. Germination occurs at a slower rate than cool-season grasses, so the two types should not be seeded together (USDA-NRCS, 1996).

2.1. c. Planting rates

Recommended planting rates are 1.12 to 2.24 kilograms (kg) pure live seed (PLS) per hectare (ha) (1 to 2 lb PLS/acre) (Ahring et al., 1978; Sims and Dewald, 1982). Under optimum conditions, 0.56 kg PLS/ha or 33 seeds per meter (m) (10 seeds per ft) of row provided adequate stands, with 1.12 to 2.24 kg PLS/ha (66 to 131 seeds per m or 20 to 41seeds per ft of row) required for less favorable conditions (Sims and Dewald, 1982). Using a rate of 2.24 kg PLS/ha (2 lb PLS/acre) is probably safest for most pasture plantings (Dalrymple, 1991; Wolf et al., 1996). Hodges and Bidwell (1993) recommend planting at 1.12 to 3.36 kg PLS/ha (1 to 3 PLS) and Ball et al. (1991) recommend planting at 2.24 to 3.36 kg/ha (2 to 3 lb/acre). An adequate stand will result when there are 9 to 13 seedlings per m (3 to 4 seedlings per ft) of row at the end of the growing season. An ideal seed lot for planting would contain greater than 50% PLS (Wolf et al., 1996).

2.1. d. Planting methods

It is best to purchase debeareded seed from a reputable dealer (see seed production below) (Wolf et al., 1996). Seeds can be broadcast or drilled (Ahring et al., 1978); however, the light weight of the seed makes it difficult to obtain uniform distribution with a broadcast seeder (Wolf et al., 1996). Recommended row spacing for pastures are 18 to 30 cm (7 to 12 in) with a wider spacing used for seed production fields (see seed production below) (Sims and Dewald, 1982). Use of a grassland drill with a chaffy seed box is recommended (Ahring et al., 1978; Hodges and Bidwell, 1993; USDA-NRCS, 1996). Seeds can be mixed with fertilizer, an inert carrier, or coated with a granulating material to allow planting with a conventional drill or improve distribution of broadcast seedings (Ahring et al., 1978). Wolf et al. (1996) recommend using a 50:50 mixture of soybean oil meal and triple superphosphate. Seed should be drilled 0.6 to 1.2 cm (0.25 to 0.5 in) deep (Ahring et al., 1978). Wolf et al. (1996) and Hodges and Bidwell (1993) recommend planting seeds less than 0.6 cm (0.25 in) deep. When no-till seeding, it is crucial that seeds are placed 1.2 cm to 1.9 cm (0.5 to 0.75 in) deep in the soil, not on top of the residue (Dalrymple, 1991). No-till planting should be delayed until the soil surface is fairly dry, which will allow the planter to cut cleanly through the residue without dragging it into the furrow (Wolf et al., 1996). The press wheels should firmly pack the row behind no-till and conventional drills (Ahring et al., 1978; Dalrymple, 1991). Rainfall can be utilized to further firm the planting furrow (Dalrymple, 1991; Wolf et al., 1996). Applying water or liquid fertilizer in the furrow while planting may increase establishment (Dalrymple, 1991). Seeds that are broadcast should be firmed into the soil by cultipacked or (Ahring et al., 1978, Wolf et al., 1996) with bulldozer tracks (USDA-NRCS, 1996) or tractor tires (Dalrymple, 1991). Under optimum

conditions, seedlings will emerge within 10 days of planting (Ahring et al., 1978). Seedlings develop at a much faster rate than most native grasses (Hsu et al., 1985). Moser and Nelson (1983) found that Caucasian bluestem seedlings developed nearly as quickly as the annual weed giant foxtail (*Setaria faberi* Herrm.), but a slower leaf elongation rate resulted in giant foxtail seedlings that were more vigorous. Seedlings are quite sensitive to drought and other stresses during the early growth stage (up to 4 leaves). Plants will begin to tiller after the 4-leaf stage (2 weeks or more after planting) (Dalrymple, 1991). Weed competition adversely affects establishment (Marietta and Britton, 1989). Weed growth can be controlled during the establishment phase with cultivation, herbicides, or limited livestock grazing (Ahring et al, 1978; Dalrymple, 1991). Pre-emergence herbicides such as atrazine are not labeled for Old World bluestems, however, plants show tolerance to this herbicide (Dalrymple, 1991). McKenna et al. (1991) found that 1.1 kg ai/ha atrazine did not adversely affect Caucasian bluestem seedlings.Low rates of 2,4-D and metsulfuron methyl can be used post-emergence to control broadleaf weeds. Seedlings should be at least 5 to 10 cm (2 to 4 in) tall before applying 2,4-D. Metsulfuron methyl should only be sprayed on Conservation Reserve Program (CRP) fields. Picloram and dicamba can be used to control broadleaf weeds when plants are past the tillering stage, but will cause more seedling injury than 2,4-D (Dalrymple, 1991). Grassy weeds can be controlled post-emergence by grazing or mowing (Dalrymple, 1991; Wolf et al., 1996). Seedling establishment may be improved by banding nitrogen (N) and phosphorus (P) starter fertilizers with the seed (Dalrymple, 1991; Sims and Dewald, 1982) at a rate of 22.4 kg N/ha (20 lb/acre) and 22.4 to 56 kg P/ha (20 to 50 lb/acre). When the plants begin to tiller, topdress with 56 to 84 kg N/ha (50 to 75 lb/acre). In Virginia, Wolf et al. (1996) recommend applying P and K at planting only if soil tests indicate lower than medium levels and that N is seldom needed in the establishment year. If seedling growth is slow and plants are chlorotic, they recommend applying 34 to 45 kg N/ha (30 to 40 lb N/acre). Grasshoppers (Dalrymple, 1991; Wolf et al., 1996), crickets and corn flea beetles can damage seedlings (Wolf et al., 1996). There are no insecticides labeled for Caucasian bluestem, however, a granular formulation of terbufos placed in the planting row at a rate of 0.56 kg ai/ha (0.5 lb ai/acre) has been shown to provide effective control (Wolf et al., 1996). McKenna et al. (1991) found that a 1.1 kg ai/ha granular carbofuran insecticide treatment applied in the planting row significantly increased seedling growth and establishment. It is recommended that newly established pastures be grazed the first winter to remove residue and to trample in seeds to encourage further stand development (Dalrymple, 1991).

2.1. e. Seed production

Seed ripening of Old World bluestems is indeterminate (Ahring et al., 1978; Sims and Dewald, 1982) and seed set of Caucasian is poor. Because many Old World bluestem strains are composed of several ecotypes or accessions, the composition of the strain may change with succeeding generations (Ahring et al., 1978). As noted previously, Caucasian is not a blend and therefore, this problem should not be encountered. Stands planted for seed production should be located on fertile soils and irrigation water should be available. Seeds should be sown in 91 to 107 cm (36 to 42 in) rows (refer to the planting methods above). If fields are planted early (March to May) then seeds can be harvested once during the establishment year, and irrigated fields can be harvested twice in each subsequent year. In Oklahoma, Caucasian bluestem will produce its first seed crop in late June or early July and a second in September to early November. Seed yields are generally higher for the fall harvest, mainly because the plant canopy interferes with harvesting operations in the summer. Plains yellow bluestem generally produces more seed than Caucasian. Best seed yields usually result when fertility is maintained to produce only moderate amounts of vegetative growth. In Oklahoma, irrigated seed production fields are fertilized in early April and again in August after seed harvest at a rate of 66 to 112 kg N/ha (60 to 100 lb/acre); dryland fields are fertilized with 66 to 134 kg N/ha (60 to 120 lbs/acre) once or twice annually. If needed, fields can be irrigated with 8 to 10 cm (3 to 4 in) of water

when plants are in full leaf to boot stage of each crop. Irrigation should cease when plants enter the boot to early head emergence stage. Seeds should be harvested when 20 to 30 percent of the heads strip off easily by hand. Due to the chaffy nature of the seeds, they are difficult to harvest with a standard combine, but plants can be topped and then threshed or hammermilled or seeds can be harvested with a seed stripper. Seed yields in excess of 224 kg per harvest per hectare (200 lb/acre) can be expected (Ahring et al., 1978). 'WW-Iron Master' produces less seed than other cultivars so seed prices will be higher (Hodges and Bidwell, 1993). One pound (0.45 kg) of pure Caucasian bluestem seed contains approximately 1,000,000 of chaffy seed units. Clipping or hammermilling and air-screen cleaning can measurably improve seed quality and planting success (Ahring et al., 1978). However, the chaffy seed appendages can help protect seeds from environmental stresses and planting unprocessed seeds may therefore reduce the chance of stand failure (Dalrymple, 1991). 'King Ranch' seeds do not reach maximum germination until 30 to 60 days after harvest, so it is recommended that seed testing be delayed for at least 60 days (Webster and Foster, 1949). There are no reports of the time required for Caucasian bluestem seeds to reach maximum germination, but it would probably be a good idea to wait a similar length of time before attempting germination testing. Residual plant material should be mowed and baled after the first harvest. Fields can be hayed or grazed after the fall harvest, but it may be best to leave the residue and burn sometime around the following March. Plains can have a problem with seed blasting, but this problem is not seen on Caucasian. Ergot and seed smut may be occasional problems. Cultivation to destroy volunteer seedlings will be necessary for cultivars and strains of Old World bluestems that are composite blends (Ahring et al., 1978).

2.2. Management

2.2. a. Yields

A pasture established using recommended methods has the potential of yielding 6720 kg/ha (3 tons/acre) of forage in the first year (Dalrymple, 1991, Wolf et al., 1996) and from 6720 to 11200 kg/ha (3 to 5 tons/acre) in later years (Dalrymple, 1991). A normal yield in most years will be 4480 to 6720 kg/ha (2 to 3 tons/acre) (Hodges and Bidwell, 1993). Caucasian is one of the first of the Old World bluestems to produce a usable forage crop in the establishment year (Dalrymple et al., 1984), however, Caucasian is less palatable to livestock than other Old World bluestem types (Ahring et al., 1978; Dabo et al., 1988; Taliaferro et al., 1972). Cornelius (1946) obtained a yield of 7893 kg /ha (7047 lb/acre) from a single clipping in August. Caucasian bluestem was the highest yielding of all grasses in this test conducted in Kansas. Yields reported in Louisiana ranged from 10823 to 13021 kg /ha (9633 to 11626 lb/acre), depending on soil fertility levels (Taylor and Meche, 1984). Amount of forage produced was much higher for Caucasian than 'King Ranch', Plains (Table 1) (Taliaferro et al., 1972) and several other Old World bluestem selections (Dalrymple et al., 1984). When soil moisture is adequate, forage yields of Caucasian bluestem are higher than 'WW-Spar', however, when soil moisture is limiting, the reverse is true (Coyne and Bradford, 1986). Caucasian enters quiescence earlier than 'WW Spar' yellow bluestem when exposed to extreme drought and high temperatures, however, it is better able to utilize excess precipitation, which indicates it may be one of the best Old World bluestems for the Southeastern states. Water use efficiency was higher than that recorded for most C_4 perennial grasses and was more comparable to a C_4 annual grass (Coyne and Bradford, 1984). Forage yields measured for Caucasian bluestem were lower than those of eastern gamagrass [*Tripsacum dactyloides* (L.) L.] (Table 2) (Faix et al., 1980). Gerrish et al. (1987) found that Caucasian bluestem produced less dry matter than switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* Vitman) or indiangrass [*Sorghastrum nutans* (L.) Nash]. However, another study showed that average total yields of Caucasian bluestem compared favorably to those of 'Pathfinder switchgrass (Table 3) (Anderson and Matches, 1983). In West Virginia, Caucasian bluestem produced similar forage yields on a soil with a water storage capacity of 16.6 cm as on one with 6.25 cm water storage capacity. Yields of 'Ky-1625'

switchgrass although much higher on the soil with the higher water storage capacity were about the same as those of Caucasian on the soil with the lower water holding capacity (Stout et al., 1986). Brejda et al. (1995) found that yields of Caucasian bluestem varied greatly between years of testing and appeared to be dependent upon precipitation amounts and patterns. In some years it produced more forage than 'Rumsey' indiangrass, whereas in other years it produced less, even with an extra cutting.

Table 1. Comparative Forage Yields of Plains, King Ranch (K.R.) and Caucasian Old World Bluestems at Perkins, Oklahoma. Vanoss Fine Sandy Loam Soil. (From Taliaferro et al., 1972).

	Tons Dry Forage/Acre				Yield as % of	
Variety	1969	1970	1971	AVG	K.R.	Caucasian
Plains	3.88	5.01	6.43	5.11	153	83
King Ranch[1]	2.86	3.80	---	3.33	100	54
Caucasian	5.16	5.56	7.67	6.13	183	100
LSD.05	0.87	0.99	0.62			

[1]The stand of K.R. was badly depleted in 1970 due to winterkill and disease. Volunteer contaminate plants derived from seed from adjacent plots accounted for most of the yield. K.R. plots were not clipped in 1971.

Table 2. Three-year (metric ton/ha) summary of Asiatic bluestems and an Eastern gamagrass on a fragipan soil in southern Illinois. (From Faix et al., 1980).

	Year			
Cultivar	1975	1976	1977	Average
Caucasian bluestem	9.50 a[1]	11.47 bc	15.21 b	12.06 b
Oklahoma B bluestem	10.51 a	10.61 bc	15.09 b	12.07 b
Oklahoma L bluestem	12.17 a	11.31 bc	16.20 b	13.23 b
Oklahoma LL bluestem	11.36 a	8.25	15.45 b	11.69 b
Oklahoma T bluestem	9.50 a	12.02 bc	13.43 b	11.65 b
Plains bluestem	11.07 a	14.98 b	12.78 b	12.94 b
Eastern gamagrass PM-K-24	7.49 b	24.33a	21.20 a	17.67 a
Average	10.23 b[1]	13.28 a	15.62 a	

[1]Values without letters in common are significantly different (Duncan's multiple range test, $P<.05$).

Table 3. Dry matter yields (first harvest + regrowth) of switchgrass and caucasian bluestem as influenced by height of cutting and date for first cutting, 1975-1977 (From Anderson and Matches, 1983)

Stubble height	First harvest date	Total dry matter yield			
		Year			
		1975	1976	1977	3-year average
Cm		kg/ha			
			Switchgrass		
8	28 May	8,720	6,670	7,740	7,620
	4 June	8,710	7,130	7,630	7,820
	11 June	9,810	7,080	7,830	8,240
	18 June	10,670	7,700	8,510	8,960
	25 June	11,340	7,690	8,260	9,100
23	28 May	6,190	4,380	4,760	5,110
	4 June	5,970	4,360	5,180	5,170
	11 June	6,100	4,240	5,320	5,220
	18 June	6,460	4,240	5,090	5,260
	25 June	6,630	4,380	5,080	5,370
LSD	(0.05)	331	449	338	357
			Caucasian bluestem		
8	11 June	7,700	6,120	9,160	7,660
	18 June	8,520	6,140	10,300	8,310
	25 June	10,500	5,410	9,400	8,430
	2 July	11,440	5,890	8,520	8,610
	9 July	12,860	5,970	9,430	9,420
23	11 June	5,080	4,560	5,460	4,970
	18 June	5,250	4,700	6,170	5,370
	25 June	5,290	4,500	5,740	5,170
	2 July	6,370	3,900	5,750	5,350
	9 July	7,030	4,480	6,160	5,890
LSD		287	398	385	349

2.2. b. Clipping frequency

Old World bluestems need to be clipped or grazed because accumulation of great amounts of plant material damages the plant stand (Dalrymple, 1991). Caucasian bluestem will not green-up until about 8 weeks after cool-season forage grasses in the mid-Atlantic states (Wolf et al., 1996). In Oklahoma, Caucasian will begin growth in April, earlier than Plains. *Indica* types initiate growth later in the spring than Caucasian or Plains (Ahring et al., 1978). Caucasian bluestem flowers earlier than switchgrass, big bluestem, and indiangrass (Gerrish et al., 1987). First hay harvest should be taken at the late boot stage. In Virginia, recommended first cut is mid to late June, with a second in early August and, if the field will not be grazed in the winter, a third about two weeks before frost (Wolf et al., 1996). In Louisiana, Taylor and Meche (1984) clipped Caucasian bluestem four times at anthesis, with the first clipping on June 13 and the fourth on December 12. Yields from the first clipping may have been increased if it had been delayed somewhat. A study in Missouri showed that Caucasian bluestem produced

75% of its total growth after June 1. Average total yields were highest when first harvest was delayed 28 days (Table 3). Harvesting at the early joint stage resulted in greater regrowth potential (Anderson and Matches, 1983). In West Virginia, annual forage yields of Caucasian bluestem and bermudagrass (*Cynodon dactylon* L. 'Quickstand') were higher than those of the more upright growing flaccidgrass (*Pennisetum flaccidum* Griseb. 'Carostan') and switchgrass ('Trailblazer') when clipping began early in the season, while plants were still in the vegetative stage. When clipping was delayed until full heading, yield of flaccidgrass, switchgrass and Caucasian bluestem were comparable and bermudagrass yields were lower. Mean growth rates for Caucasian bluestem measured in this treatment were 160 kg ha^{-1} d^{-1}, lower than those of flaccidgrass (196 kg ha^{-1} d^{-1}) and switchgrass (176 kg ha^{-1} d^{-1}) (Belesky and Fedders, 1995). Taliaferro et al. (1984) found that dry matter yields increased when clipping intervals increased from 3 to 7 weeks and in most years there was no difference between the 7, 9 and 11 week clipping interval. They stated that yield responses to clipping regime are similar to those of Coastal bermudagrass. Heavy grazing results in decreased plant water usage (Svejcar and Christiansen, 1987a; Svejcar and Christiansen, 1987b). Stubble height after grazing or haying should be 8 to 15 cm (3 to 6 in) (Dalrymple, 1991); 8 to 10 cm (3 to 4 in) (Wolf et al., 1996). Caucasian bluestem clipped at a height of 8 cm had denser stands, fewer weeds and increased plant heights compared to plants clipped at 23 cm (Anderson and Matches, 1983). Caucasian bluestem produces a larger number of tillers than giant foxtail, big bluestem ('Pawnee'), or indiangrass ('Oto') and does not allocate as many food resources to its main tiller (Moser and Nelson, 1983). Caucasian bluestem produces new crown tillers continuously throughout the growing season, which gives it a high regrowth potential (Anderson and Matches, 1983; Forwood et al., 1988). These tillers are packed tightly in the crown, which protects the growing points from defoliation (Christiansen and Svejcar, 1987).

2.2. c. Fertility

Caucasian bluestem responds to N (Ball et al., 1991; Dalrymple et al., 1984; Hodges and Bidwell, 1993; Jung et al., 1990; Sims and Dewald, 1982); however, it will produce adequate forage with less N than is required for cool-season grasses (Jung et al., 1990; Wolf et al., 1996) or bermudagrass (Wolf et al., 1996). Caucasian bluestem is a good scavenger of nutrients (Brejda et al., 1995; Dalrymple et al., 1984; Wolf et al., 1996). Plants require only medium levels of P and K (Wolf et al., 1996). Fertilization with 67 kg N/ha (60 lb N/acre) increased forage production of Caucasian bluestem subjected to repeated clipping. Other research showed that fertilization with either 56 kg/ha (50 lb/acre) of N alone or 112-67-67 kg N-P-K/ha (100-60-60 lb N-P-K/acre) were the best fertilization rates for south-central Oklahoma (Sims and Dewald, 1982). In some testing years, forage yields on plots receiving a single application of 67 kg N/ha (60 lb/acre) in April were just as good as those receiving split applications (Hodges and Bidwell, 1993). In Virginia, if early growth rates are poor, N may be applied at 56 kg/ha (50 lb/acre) in mid May, with a second application at the same rate made in late June. Old World bluestems will produce 9 to 23 kg (20 to 50 lb) of additional biomass for each 0.45 (1 lb) of actual N applied. Nitrogen rates on irrigated sites should be higher than on dryland fields. Brown et al. (1991) calculated that the optimum N rate was 106.4 kg N/ha (95 lb N/acre) to provide the maximum yield per dollar invested in N. Brejda et al. (1995) considered urea an inferior N source compared to NH_4NO_3 on shallow droughty soils in the Ozarks and there was also no benefit to using $(NH_4)_2SO_4$ as the N source. In this study, Caucasian bluestem showed no beneficial yield response to N rates above 161 kg/ha. However, another study showed that forage yields using urea as the N source were higher in one year and not different in the second year compared to NH_4NO_3. This result was attributed to excessive rainfall and nitrate leaching from the NH_4NO_3 treatment the first testing year. In this study, Caucasian bluestem did not respond to N rates above 125 kg N/ha (140 lb N/acre) (Joost and Brown, 1993). In Oklahoma, N applications are not recommended after September 1, because of the possibility of forcing the plants into active growth before winter (Hodges and Bidwell, 1993). Taylor and Meche (1984) found that yields of

Caucasian bluestem were 12 and 21% higher with residual P soil levels equal to 228 and 457 kg $P_2 0_5$/ha (204 and 408 lb $P_2 0_5$/acre) compared to the control with 0 kg $P_2 0_5$/ha.

2.2. d. Weed Control

Spring burning will provide some insect and weed control (Ahring et al., 1978). Caucasian bluestem does not respond as vigorously to fire as native grasses (USDA-NRCS, 1996). Seed production fields are cultivated to control weeds and volunteer seedlings (Ahring et al., 1978). Simazine can be used on established stands of Caucasian bluestem (Ahring et al., 1978, Wolf et al., 1996) in early May at a rate of 2.24 kg ai/ha (2 lb ai/acre). Any broadleaf weeds not controlled by simazine can be controlled using 2,4-D or dicamba (Wolf et al., 1996).

Biofuel Potential

Old World bluestems grown in the United States for forage production have a wide range of adaptation and high biomass production capability, which are desirable characteristics for a potential biofuel crop. Of these Old World bluestems, Caucasian is generally the highest yielding and would therefore target it as the best type for biofuel production, baring any local soil or environmental factors that, as noted above, would favor one of the other Old World bluestem selections. Although Caucasian has been grown in the southeastern United States, most of the research on yield potentials and management techniques was conducted in the Great Plains and in the Midwest. If it were to be promoted in the Southeast as a biofuel crop, additional plantings in this region would be recommended. The caveat always related that Caucasian is less palatable than other Old World bluestems may actually be a plus for a biofuel crop. The higher level of indigestible components in Caucasian could improve its fuel characteristics. All of the research presented on yield potentials was conducted with multiple clippings to maximize forage production. If it were to be used as a biofuel crop, optimum management practices would likely have to be determined. One advantage that Caucasian bluestem has over a native grass like switchgrass is that it can be clipped much more closely without damaging the stand. This would allow use of conventional haying equipment that most Southeast growers already possess. However, because Caucasian bluestem needs to be cut frequently to avoid damage to the stand, the cost of additional clippings may be a major factor affecting its potential use as a biofuel crop.

Questions that need to be answered before advancing Caucasian bluestem as a biofuel crop for marginal cropland.

1. What is the fuel quality of Caucasian bluestem plant matter?
2. What yields can be expected in the Southeast?
3. How infrequently can Caucasian bluestem be clipped and still maintain a healthy stand? Is it economical to clip this number of times compared to the one clip used on switchgrass?
4. Does Caucasian bluestem pose any threat to become an invasive species? Is this threat any greater than the introduced forage grasses currently used in the Southeast?
5. What fertilization rates are best for biofuel production?

Literature Cited

Ahring, R. M. Taliaferro, C. M., and Russell, C. C. 1978. Establishment and management of Old World bluestem grasses for seed. Agric. Exp. Sta., Oklahoma State Univ., Stillwater. Tech. Bull. T-149. 24 p.

Anderson, B. and Matches, A. G. 1983. Forage yield, quality, and persistence of switchgrass and

Caucasian bluestem. Agron. J. 75: 119-124.

Ball, D. M., Hoveland, C. S., and Lacefield, G. D. 1991. Southern Forages. The Potash & Phosphate Institute and the Foundation for Agronomic Research, Atlanta, GA. 256 p.

Belesky, D. P. and Fedders, J. M. 1995. Warm-season grass productivity and growth rate as influenced by canopy management. Agron. J. 87: 42-48.

Bor, N. L. 1960. The grasses of Burma, Ceylon, India and Pakistan (Excluding Bambuseae). International Series of Monographs on Pure and Applied Biology, Division: Botany, Vol 1. R.C. Rollins and G. Taylor, eds. Pergamon Press, Oxford, London. 767 p.

Brejda, J. J., Brown, J. R. and Hoenshell, C. L. 1995. Indiangrass and Caucasian bluestem responses to different nitrogen sources and rates in the Ozarks. J. Range Manage. 48: 172-180.

Brown, J. R., Hoenshell, C. L., Schumacher, W. and Brejda, J. J. 1991. Nitrogen response by Caucasian bluestem and indiangrass. 1991 Proc. Forage and Grassland Conf. 179-182.

Christiansen, S. and Svejcar, T. 1987. Grazing effects on the total nonstructural carbohydrate pools in Caucasian bluestem. Agron. J. 79: 761-764.

Cornelius, D. R. 1946. Comparison of some soil-conserving grasses. Agron. J. 38(8): 682-689.

Coyne, P. I. and Bradford, J. A. 1984. Leaf gas exchange in 'Caucasian' bluestem in relation to light, temperature, humidity, and CO_2. Agron. J. 76: 107-113.

Coyne, P. I. and Bradford, J. A. 1986. Biomass partitioning in 'Caucasian' and 'WW-Spar' Old World bluestems. J. Range Manage. 39(4): 303-310.

Dabo, S. M., Taliaferro, C. M., Coleman, S. W., Horn, F. P. and Claypool, P. L. 1988. Chemical composition of Old World bluestem grasses as affected by cultivar and maturity. J. Range Manage. 41(1): 40-48.

Dalrymple, R. L. 1991. Old World bluestem stand establishment and first year production management. Noble Foundation, Ardmore, OK. Oklahoma Coop. Ext. Service, Circular E, 17-44.

Dalrymple, R. L., Rogers, J., and Timberlake, L. 1984. Old World bluestem comparison. Noble Foundation, Ardmore, OK. Report AB-84. 16 p.

De Wet, J. M. J. and Harlan, J. R. 1966. Morphology of the compilospecies *Bothriochloa intermedia*. Amer. J. Bot. 53(1): 94-98.

Englert, J. M. and White, R. S. 1998. Improved conservation plant materials released by NRCS and cooperators through December 1997. USDA-Natural Resources Conservation Service, National Plant Materials Center, Beltsville, MD. Online URL - http://Plant-Materials.nrcs.usda.gov:90/pmc/MDPMC/rel97-syn.html.

Faix, J. J., Kaiser, C. J. and Hinds, F. C. 1980. Quality, yield, and survival of Asiatic bluestems and an eastern gamagrass in southern Illinois. J. Range Manage. 33(5): 388-390.

Forwood, J. R., Matches, A. G. and Nelson, C. J. 1988. Forage yield, nonstructural carbohydrate

levels, and quality trends of Caucasian bluestem. Agron. J. 80: 135-139.

Gerrish, J. R., Forwood, J. R. and Nelson, C. J. 1987. Phenological development of eleven warm season grass cultivars. 1987 Proc. Forage and Grassland Conf. 249-253.

Gould, F. W. 1978. Common Texas grasses an illustrated guide. Texas A&M Univ. Press, College Station. 267 p.

Gould, F. W. and Shaw, R. B. 1983. Grass Systematics. 2nd Ed. Texas A&M Univ. Press, College Station. 397 p.

Hodges, M. and Bidwell, T. G. 1993. Production and management of Old World bluestems. Oklahoma State Univ., Stillwater. OSU Extension Facts No. 3020. 4 p.

Hsu, F. H., Nelson, C. J. and Matches, A. G. 1985. Temperature effects on seedling development of perennial warm-season forage grasses. Crop Sci. 25: 249-255.

Joost, R. E and Brown, J. R. 1993. Effect of nitrogen source on N-uptake efficiency in Causasian bluestem. 1992 Proc. American Forage and Grassland Council. 2: 136-140.

Jung, G. A., Griffin, J. L., Kocher, R. E., Shaffer, J. A. and Gross, C.F. 1985. Performance of switchgrass and bluestem cultivars mixed with cool-season species. Agron. J. 77: 846-850.

Jung, G. A., Shaffer, J. A., Stout, W. L., and Panciera, M. T. 1990. Warm-season grass diversity in yield, plant morphology, and nitrogen concentration and removal in northeastern USA. Agron. J. 82: 21-26.

Marietta, K. L. and Britton, C. M. 1989. Establishment of seven high yielding grasses on the Texas High Plains. J. Range Manage. 42(4): 289-294.

McKenna, J. R., Wolf, D. D. and Lentner, M. 1991. No-till warm-season grass establishment as affected by atrazine and carbofuran. Agron. J. 83: 311-316.

Missouri Botanical Garden. 1981. Index to plant chromosome numbers 1975-1978. Monographs in systemic botany from the Missouri Botanical Garden, Vol. 5. P. Goldblatt, ed. St. Louis, MO. 553 p.

Moser, L. E. and Nelson, C. J. 1983. Strategies of seedling development in warm-season grass. Proc. XVI International Grassland Congress. 381-383.

Sims, P. L. and Dewald, C. L. 1982. Old World bluestems and their forage potential for the southern Great Plains a review of early studies. USDA-Agric. Res. Serv., Southern Plains Range Res. Sta., Woodward, OK. ARM-S-28. 15 p.

Stout, W. L., Jung, G. A., Shaffer, J. A. and Estepp, R. 1986. Soil water conditions and yield of tall fescue, switchgrass, and Caucasian bluestem in the Appalachian Northeast. J. Soil and Water Conserv. 41(3): 184-186.

Svejcar, T. and Christiansen, S. 1987a. The influence of grazing pressure on rooting dynamics of Caucasian bluestem. J. Range. Manage. 40(3): 224-227.

Svejcar, T. and Christiansen, S. 1987b. Grazing effects on water relations of Caucasian bluestem. J. Range Manage. 40(1): 15-18.

Taliaferro, C. M., Harlan, J. R., and Richardson, W. L. 1972. Plains bluestem. Oklahoma Coop. Ext., Oklahoma State Univ., Stillwater. Bull. B-699. 11 p.

Taliaferro, C. M., Horn, F. P., Ahring, R. M. and Weeks, D. L. 1984. Yield and quality of 'Caucasian' and 'Plains' bluestem grasses as affected by clipping interval. Agron. J. 76: 769-772.

Taylor, R. W. and Meche, G. A. 1984. Response of Caucasian bluestem, switchgrass, indiangrass, and big bluestem to phosphorus fertilization a preliminary report. Ann. Prog. Rep. – Louisiana Agric. Exp. Sta. 76: 400-403.

USDA. ND. WW-Iron Master Old World bluestem. Online URL – http://www.sprrs.usda.gov/wwim.htm.

USDA-NRCS. 1996. Caucasian bluestem plant fact sheet. USDA-Natural Resources Conservation Service, National Plant Materials Center, Beltsville, MD. Online URL – http://ironwood.itc.nrcs.usda.gov:90/pmc/grasses/boca.html.

USDA-NRCS. 1999. The plants database. National Plant Data Center, Baton Rouge, LA. Online URL – http://plants.usda.gov.

USDA-SCS. 1979. Notice of naming and release of 'Ganada' yellow bluestem for soil stabilization and range forage. USDA-Soil Conservation Service. 4 p.

Webster, C. B. and Foster, D. H. 1949. King Ranch Bluestem. USDA-Soil Conservation Service, Ft. Worth, TX. 14 p.

Wolf, D. D., Whiter, R. S., Tinsley, S. E. 1996. Establishing and managing Caucasian bluestem. Virginia Coop. Ext. Virginia Tech. Univ. Pub. No. 418-014. Online URL-http://www.ext.vt.edu/pubs/forage/418-014/418-014.html.