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Influence of Cereal-Legume Rotation on *Striga* Control and Maize Grain Yield in Farmers' Fields in the Northern Guinea Savanna of Nigeria

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Abstract

On-farm trials were conducted in 2001, 2002, and 2003 in the northern Guinea savanna of Nigeria to evaluate integrated *Striga hermonthica* control measures under farmer-managed conditions. These included intercropping a *Striga*-resistant maize variety with cowpea for 3 years and also cropping this maize in rotation with legume trap crops - soybean and cowpea for 1-2 two years. Intercropping *Striga*-tolerant maize variety, Acr. 97TZL Comp. 1-W, with cowpea (*Vigna unguiculata* L.) consistently reduced *Striga* infestation in maize relative to continuously cropped sole maize over the three-year period. Maize grain yield was lower in the intercrop than in the sole maize plot probably due to competition from cowpea. However, because of the high value of cowpea in the intercrop, crop value for this system was higher than sole cropped maize. Legume-maize rotation reduced *Striga* infestation by 35% after one year of legumes in the rotation and by 76% after two years of legumes in the rotation. Soybean was more effective in reducing *Striga* infestation and also gave higher maize grain yield than cowpea. The rotation of these two legumes with maize had clear advantage over continuously cropped maize. Farmers should therefore be encouraged to adopt the introduction of grain legumes into the cereal cropping systems of the Nigerian savanna.

Keywords: maize, soybean, cowpea, cereal-legume rotation, intercropping, *Striga*

1 Introduction

The parasitic angiosperm, *Striga hermonthica* (Del.) Benth is an important weed mainly of C_4 cereals in the semi-arid tropics. Maize, sorghum, and millet are the most important hosts. The parasite can also infect upland rice. It has been estimated that about 40 to 70 million ha are severely or moderately infested in West African countries (Lagoke *et al.*, 1991). Severe *Striga* infection can cause 70 - 80% crop loss in maize and sorghum and losses can be much higher under heavy infestations, even resulting in total crop failure (Riches *et al.*, 1992; Parker and Riches, 1993). Farmers often have to abandon in-

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fested agricultural lands as a result of high soil infestation by *Striga* (KROSCHEL, 1999). Recent trends away from traditional prolonged fallow and intercropping towards continuous cereal monocropping to meet the needs of increasing population have intensified the Striga problem. In addition to many factors already known, grazing cattle, crop seeds, and wind contribute to the spread of *Striga* infestation to new areas (BERNER *et al.*, 1996). The *Striga* problem is compounded by the plant's reproductive capacity. A single plant can produce over 50,000 seeds, which can remain viable in the soil for 15-20 years (MUSSELMAN, 1987; DOGGETT, 1988).

Striga research in Africa has a long history and a range of effective component control technologies has been identified (PARKER and RICHES, 1993). Examples of control options for *S. hermonthica* range from the use of leguminous trap-crops to stimulate suicidal germination of *Striga* seeds and therefore reduce the seed bank and improve soil fertility, to the use of resistant host-crop cultivars. SCHULZ *et al.* (2003) found that resistant maize following a soybean trap-crop yielded 1.58 t ha^{-1} of grain and outyielded farmers' maize variety following traditional practices by more than 80%. The effectiveness of leguminous trap-crops in reducing the *Striga* seed bank was demonstrated by SAUERBORN (1999) in field experiments in Ghana where annual double cropping of trap-crops (soybean, sunflower and cotton) reduced the seed bank by about 30% each year. Similarly, SCHULZ *et al.* (2003) achieved 50% seed bank reduction after one year's rotation with soybean and cowpea under farmer-managed conditions. CARSKY *et al.* (2000) reported that *S. hermonthica* incidence in maize after soybean, compared to maize after sorghum, was significantly reduced from 3.2 to 1.3 emerged plants per maize plant, resulting in greatly improved grain yields.

In addition to host-plant resistance and legume trap-crops, a substantial amount of work has been carried out to study the effect of soil fertility on *Striga* infestation. Infestation is frequently associated with low soil fertility (CARSKY *et al.*, 2000; SCHULZ *et al.*, 2003). Hence, improved soil fertility conditions are likely to lead to reduced infestation (DEBRA *et al.*, 1998). The use of grain legumes can contribute to soil N (CARSKY and IWUAFOR, 1999). Estimates of fertilizer replacement values in a monomodal savanna zone of West Africa were 20 kg N ha^{-1} from soybean and 45kg N ha^{-1} from cowpea (KALEEM, 1993; CARSKY *et al.*, 1997). SANGINGA *et al.* (21001) reported that the grain yield of maize grown after soybean was increased by an average of 25% across two locations. They attributed this to enhanced N availability following soybean and other rotation effects, such as the reduction of soil-borne diseases. Intercropping, particularly of cereals with cowpea (*Vigna unguiculata*), is a common practice in many parts of the semi-arid zone. This is because food production is diversified, the risk of crop failure reduced, and resources for crop growth are utilized more efficiently compared to sole cropping (CARSKY *et al.*, 1994). Intercropping of cereals with legumes has also been proposed as a means of suppressing *Striga* in the cereal crop (VERNON, 1995; KUREH *et al.*, 2000). CARSON (1989) found that the density of emerged *Striga* plants, and soil temperature were both reduced when sorghum was associated with groundnut in Gambia.

Most *Striga*-infested areas already have high levels of the parasite seeds in the soil. The adoption of control measures that aim to reduce the level of this *Striga* seed inoculum has to be encouraged. The potentials of cereal-legume rotation and intercropping to manage *Striga* infestation in cereals has been demonstrated under controlled, researcher-managed conditions. It is therefore necessary to demonstrate that these technologies work efficiently under farmer-managed conditions and are indeed appropriate for African farmers (FISHER, 1999). The present study is a long-term farmer-managed *Striga* control project comparing short- and long-term rotation of a *Striga*-resistant maize with soybean and cowpea. Controls were maize intercropped with soybean and continuous cropping with *Striga*-resistant maize.

2 Materials and Methods

The trials were established with farmer management on 12 farmers' fields selected in two neighboring villages in Kaduna State, (northern Nigeria) in 2001, 2002, and 2003. The fields are located in the northern Guinea savanna zone, which is characterized by a sub-humid climate with monmodal rainfall of 900-1200mm, which extends over an annual growing period of 150-180 days. Rainfall was 1322 mm in 2001, 1007 mm 2002, and 1135 mm in 2003. The main characteristics of the soils are presented in Table 1.

Table 1: Soil properties in the trial sites.

Property	*Ungwan Shamaki*	*Tasha Kaya*
pH ($CaCl_2$)	5.1	4.9
Total N (g kg^{-1})	0.2	0.08
Organic Carbon (g kg^{-1})	4.8	5.0
Bray 1-P (mg kg^{-1})	3.75	5.1

All trials were conducted on sites infested with *Striga hermonthica* and simultaneously served as demonstration plots for participating farmers. The treatments were as follows:

(i) Cowpea-maize intercrop,
(ii) one year of soybean followed by two years of maize,
(iii) one year of cowpea followed by two years of maize,
(iv) two years of soybean followed by one year of maize,
(v) two years cowpea followed by one year of maize and
(vi) continuous sole cropped maize as control.

The maize used was an improved *Striga*-tolerant open-pollinated maize variety (Acr. 97TZL Comp1-W). The soybean was an *Alectra*-tolerant and high N-fixing variety (TXG1448-2E) while the cowpea used in the intercrop was a *Striga*-tolerant early-maturing variety (IT93K452-1). The two legume varieties have been found to cause suicidal germination of *Striga* in screen house experiments (BERNER *et al.*, 1996). The experimental arrangement in each farmer's field is illustrated in Table 2.

Table 2: Arrangement of treatments on farmers' fields.

Location	*Year 1*	*Year 2*	*Year 3*
1	Resistant Maize	Resistant Maize	Resistant Maize
2	Soybean	Resistant Maize	Resistant Maize
3	Soybean	Soybean	Resistant Maize
4	Cowpea	Resistant Maize	Resistant Maize
5	Cowpea	Cowpea	Resistant Maize
6	Cowpea-maize intercrop	Cowpea-maize intercrop	Cowpea-maize intercrop

The trials were successfully established on eight farmers' fields at Ungwa Shamaki and four at Tashan Kaya. The villages were less than 5 km from each other and had similar soil and climatic conditions. Each farm with the six plots constituted a replicate. The gross plot size was $150m^2$ and the net size was $135m^2$. In 2001, each crop was planted on ridges as a sole crop except for the maize-cowpea intercrop treatment. Maize was sown at 3 seeds per hill at a spacing of 75×50 cm. At two weeks after sowing (WAS), maize was thinned to two plants per stand. Soybean was drilled at a spacing of 5 cm on ridges with 75 cm interspace. In the sole cowpea variant, two seeds were planted on ridges at a spacing of $\times$ without thinning but in the intercrop variant one stand of cowpea was planted between two maize stands. In 2002 and 2003, the same operations were performed as in 2001.

All crops were hoe weeded at 3 and 6 WAS followed by a careful hand-pulling of other annual weeds except *Striga*.

Fertilizer was applied at the recommended rate of 100 kg N/ha, 50kg P/ha and 50kg K/ha using NPK and urea. The nitrogen fertilizer was split-applied at 3 and 6 WAS. Fertilizer was applied to soybean and cowpeas at the rate of 20kg N/ha, 40kg P/ha, and 20kg K/ha at 2 WAS using NPK (20:10:10), single superphosphate and muriate of potash. The cowpeas were sprayed with Cyper Plus (250 g Cypermetrin/ha) at the rate of 1 l/ha at flower bud initiation and Benlate (3 g Benomyl/ha) was applied at 0.4 kg/ha during podding to control fungal diseases and insect pests.

Data collected included maize stand count, *Striga* shoot count (infestation), number of maize plants infested (incidence), host damage severity on a scale of 1-9 (where 9 $\widehat{=}$ completely dead plants), and grain yield of maize, soybean and cowpea. Crop value in the systems was calculated using the Naira (₦, Nigerian currency) prices for the component commodity crops. The data were subjected to analysis of variance and treatment means were compared using Duncan Multiple Range Test (DMRT). Data on yield of soybean are not reported in this paper since they are not harvested from the same plot as maize.

Table 3: Effects of sole and intercropping on plant population, *Striga* infestation, crop damage severity and grain yield of maize on farmers' fields in northern Nigeria (2001).

Cropping system	*Maize* (plants/ha)*	*Striga* (no./ha)*	*Infested maize* (plants/ha)*	*Crop damage† severity (1-9)*	*Maize grain yield (kg/ha)*	*Maize value (₦)‡*	*Cowpea seed yield (kg/ha)*	*Cowpea value (₦)§*	*Total value (₦)*
Sole maize	$21{,}013^{a}$	1158.3^{a}	414.6^{a}	2.33^{a}	810.42^{a}	16,208	-	-	16,208
Maize-cowpea intercrop	$17{,}371^{b}$	433.3^{b}	295.8^{b}	2.58^{b}	613.54^{a}	12,270	306	9,180	21,450

* at 12 WAS (weeks after sowing)
† Crop damage severity using a scale of 1 - 9, where 1 ≘ healthy plants and 9 ≘ completely dead plants
‡ at ₦20/kg, § at ₦30/kg

Table 4: Effects of previous crops on plant population, *Striga* infestation, crop damage severity, and grain yield of maize on farmers' fields in northern Nigeria in the second year (2002).

Cropping system‡	*Maize** *(plants/ha)*	*Striga** *(no./ha)*	*Infested maize** *(plants/ha)*	*Crop damage*† *severity (1-9)*	*Maize grain yield (kg/ha)*	*Maize value (₦)*§	*Cowpea seed yield (kg/ha)*	*Cowpea value (₦)*¶	*Total value (₦)*
M–M	21,433^{c}	1191.7^{a}	343.8^{a}	4.08^{a}	1147.6^{b}	22, 952	–	–	22,952
S–M	22,954^{ab}	772.9^{b}	272.9^{b}	3.50^{b}	1468.4^{a}	29,360	–	–	29,360
C–M	23,988^{a}	1025.0^{ab}	431.3^{ab}	3.67^{b}	1384.0^{a}	27,680	–	–	27,680
Maize-cowpea intercrop	22,513^{bc}	375.0^{b}	202.1^{b}	4.17^{a}	782.5^{c}	–	697	27,880	43,530

* at 12 WAS (weeks after sowing)
† Crop damage severity using a scale of 1 - 9, where 1 ≘ healthy plants and 9 ≘ completely dead plants
‡ M–M ≘ sole maize, S–M ≘ maize after soybean, C–M ≘ maize after cowpea
§ at ₦20/kg, ¶ at ₦30/kg
Means followed by the same letter(s) within a column are not significantly different at 5% level of probability (DMRT).

Table 5: Effects of previous crops on plant population, *Striga* infestation, crop damage severity, and grain yield of maize on farmers' fields in northern Nigeria in the third year (2003).

Cropping system	*Maize* (plants/ha)*	*Striga* (no./ha)*	*Infested maize* (plants/ha)*	*Crop damage† severity (1-9)*	*Maize grain yield (kg/ha)*	*Maize value (₦)‡*	*Cowpea seed yield (kg/ha)*	*Cowpea value (₦)§*	*Total value (₦)*
M–M–M	$23{,}022^{b}$	489^{a}	273^{a}	4.5^{a}	1167^{c}	23,400	–	–	23,400
S–M–M	$23{,}296^{a}$	291^{ab}	173^{ab}	3.8^{ab}	1569^{bc}	31,380	–	–	31,380
C–M–M	$23{,}216^{a}$	293^{ab}	178^{ab}	4.1^{a}	1398^{c}	27,960	–	–	27,960
S–S–M	$23{,}263^{a}$	111^{b}	98^{b}	3.3^{b}	2185^{a}	43,700	–	–	43,700
C–C–M	$23{,}076^{b}$	121	^{b} 86^{b}	3.7^{ab}	1939^{ab}	38,780	–	–	38,780
M–C intercrop	$22{,}611^{c}$	94^{b}	73^{b}	4.1^{a}	1400^{c}	28,000	680	27,200	55, 200

* at 12 WAS (weeks after sowing)
† Crop damage severity using a scale of 1 - 9, where 1 ≘ healthy plants and 9 ≘ completely dead plants
‡ M–M–M ≘ maize–maize–maize, S–M–M ≘ soybean–maize–maize, C–M–M ≘ cowpea–maize–maize, S–S–M ≘ soybean–soybean–maize, C–C–M ≘ cowpea–cowpea–maize
§ at ₦20/kg, ¶ at ₦30/kg
Means followed by the same letter(s) within a column are not significantly different at 5% level of probability (DMRT).

3 Results

3.1 Sole and intercropping effects on Striga and maize in the first year

In 2001, the sole-cropped and intercropped maize exhibited similar low levels of crop damage severity. The sole maize had better plant establishment than the intercropped maize although these were planted at the same density. *Striga* infestation and incidence were lower when maize was intercropped with cowpea than when planted sole. However, maize grain yield was 32% higher (not significant different at 5%) when planted solecompared to intercropped with cowpea (Table 3).

3.2 Effects of one-year rotation on Striga infestation and maize grain yield

In 2002, plant population at harvest was generally lower than optimal for all treatments. Maize grown after one year of soybean and cowpea had a significantly higher plant population than the intercropped and continuously cropped maize. The number of emerged *Striga* was significantly higher in continuously cropped maize compared to maize after one year of soybean and cowpea intercropped maize (Table 4). *Striga* infestation was 70% lower in intercropped maize, 54% lower in maize after soybean, and 16% lower in maize after cowpea compared to continuously cropped maize. Crop damage severity was similar and higher in continuously cropped and intercropped maize than in maize after soybean and cowpea.

Maize after one year of soybean and maize after one year of cowpea had significantly higher grain yield than the intercropped and continuously cropped maize. Maize grain yield was 28% higher after one year of soybean and 21% higher after one year of cowpea than in the continuously cropped maize. Continuously cropped maize recorded 47% higher grain yield than the intercropped maize (Table 4). However, intercropping maize with cowpea produced 90% more crop value than sole cropped maize.

3.3 Effects of two-year rotation on Striga infestation and maize grain yield

Plant population at harvest was generally lower than the recommended practice for all treatments in 2003 (Table 5). The number of emerged *Striga*/ha was significantly higher in continuously cropped maize than in maize grown after two years of soybean or cowpea and intercropped maize. *Striga* number was 81% lower in intercropped maize, 77% lower in maize after two years soybean, and 75% lower in maize after two years of cowpea than in continuously cropped maize. *Striga* number/ha in maize after two years of soybean was 62% lower than in maize after one year of soybean. *Striga* number/ha in maize after two years of cowpea was 59% lower than in maize after one year of cowpea. *Striga* number in maize continuously cropped for two years after one year of soybean or cowpea was 40% lower than in maize continuously cropped for three years without rotation with legumes. Continuously cropping the *Striga*-resistant/tolerant maize for three years reduced number of emerged *Striga*/ha by 57%. Crop damage severity in maize after two years of soybean was significantly lower than in all other treatments. Cropped damage severity in continuously cropped and intercropped maize increased with years of cultivation. However, crop damage scores were generally low for all treatments.

Maize grain yield after two years of soybean was 87% higher than maize continuously cropped for three years. Maize grain yield after two years of cowpea was 67% higher than the continuously cropped maize. Maize grain yield in maize-cowpea intercrop was 20% higher than the continuously cropped maize. Seed yield of cowpea in the intercropped was relatively lower than that normally obtained for sole crop of the cowpea variety used in this trial. Continuous cropping of maize for two years after one year of soybean and cowpea recorded grain yield 34 and 19% higher than maize continuously cropped for two years respectively. Maize grain yield after two years of soybean was 32.8% higher than maize grain yield after one year of soybean. Maize grain yield after two years of cowpea was 28.6% higher than maize after one year of cowpea. Intercropping maize with cowpea on the same plot for three years produced 136% more crop value than sole cropped maize.

3.4 Effects of previous crops on total soil nitrogen and available phosphorus

The effect of previous crops on total soil N at 0 to 10 cm depth is summarized in Table 6. Total N in the previous soybean and cowpea plots, and the intercropped maize plots was higher than in the continuously cropped maize plots. Mean total N in the plots previously cropped to legumes or intercropped with cowpea was 20% higher than the continuously cropped maize. There were no significant differences between previous soybean, cowpea, and maize-cowpea intercrops. Previous soybean and cowpea contributed similar amounts of N to the soil at all locations. Available P values in the soil were higher in plots previously cropped to soybean, cowpea or maize-cowpea intercropped than in continuously cropped maize. Average P values in plots after two years of soybean or cowpea were 70% higher than in continuously cropped maize. After one year of soybean or cowpea, average P values were 20% more than in continuously maize. P availability in maize-cowpea intercropped was not significantly different from two years of cowpea or soybean.

Table 6: Effect of previous crop on total soil nitrogen and available phosphorus before maize planting in 2003.

Treatments	*total* N *(g/kg)*	*avail.* P *(mg/kg)*
2 years sole maize	0.68	4.86
1 year soybean followed 1 year maize	0.79	4.99
2 years sole soybean	0.81	9.38
1 year cowpea followed by 1 year maize	0.81	6.91
2 years sole cowpea	0.83	7.18
2 years maize/cowpea intercrop	0.84	7.69
Mean	0.79	6.84
S.E.	0.02	0.79

4 Discussion

The trials demonstrated the potential of appropriate soybean and cowpea cultivars to reduce *Striga* parasitism in subsequent maize. It also demonstrated the potential of maize-cowpea intercrops to control *Striga*. The two legume cultivars used were able to reduce *Striga* parasitism in the rotation systems. Intercropping maize with cowpea reduced emerged *Striga* density. This reduction may be due to shading effects from the cowpea canopy. CARSON (1989) reported a positive relationship between soil temperatures under groundnut intercropped with sorghum and emerged *Striga* density. He found that the soil temperature at a depth of 10 cm at 6 to 7 weeks after sorghum emergence was about 2°C lower in sorghum rows and that *Striga* density at sorghum harvest was reduced by 60 to 70% in the treatment with sorghum and groundnut in the same row. CARSKY *et al.* (1994) reported that the number of mature capsule-bearing *Striga* plants was low when the cowpea ground cover was high in a sorghum-cowpea intercrop. This suggests that any spatial arrangement that increases cowpea ground cover at the base of maize or sorghum can reduce the density of mature *Striga*. CARSKY *et al.* (1994) therefore, concluded that in the long term, this might reduce the density of *Striga* seed, provided no importation of *Striga* seed to the field were allowed. They also found no significant reduction in sorghum yield by intercropping sorghum with cowpea. In the present study, intercropping cowpea with maize reduced maize yield by 47% despite the reduction in the number of emerged *Striga*. This may be due to a competition effect from the cowpea crop on the maize crop. This corroborates the findings of KUREH *et al.* (2000) and KUCHINDA *et al.* (2003). When maize and cowpea are planted at the same time in intercropping systems, the fast growing and profuse branching cowpea competes with the maize crop for light, water, and nutrients. This slows than maize growth considerably thereby reducing yield. Maize and sorghum appear to have different reactions to competition effects from other crops in intercropping systems. Maize has a shorter maturity period than sorghum. Hence, sorghum may overcome the effects of intercropping long after the cowpea has been harvested. Intercropping maize with cowpea is a good agronomic practice for *Striga* management due to reduced *Striga* infestation and high total crop value. KUREH *et al.* (2000) similarly reported better *Striga* management and increased crop value when soybean is intercropped with maize.

Despite the considerable reduction in maize yield when intercropped with cowpea, this system recorded higher crop value than the sole cropped maize in both rotation with legumes or when continuously cropped. Grain yield reduction of maize when intercropped with cowpea was compensated for by the higher cash value of cowpea in the intercropping system. Because of this reason, intercropping may continue to be one of the options for *Striga* control.

Several studies have shown a significant reduction in *Striga* attack by adopting cropping systems that include intercropping and rotations (CARSKY *et al.*, 1994, 2000; SCHULZ *et al.*, 2003; KUCHINDA *et al.*, 2003). Several other mechanisms can be suggested to explain the reduction of *Striga* when maize is intercropped or rotated with legume trap crops. In addition to shading out *Striga* in intercropping systems, the cowpea or soybean has been shown to stimulate the germination of *Striga* without acting as hosts

(Carsky *et al.*, 1994; Berner *et al.*, 1996; Carsky *et al.*, 2000; Kureh *et al.*, 2000; Kuchinda *et al.*, 2003). In this study, the extent of reduction in *Striga* infestation was dependent on the type of legume and number of years soybean or cowpea were cultivated before maize cultivation. For example, *Striga* infestation was 54% lower after one year of soybean and 16% lower after one year of cowpea. However, in the second year, there was higher level of reductions when the legumes were cultivated for two years before maize was cultivated. *Striga* infestation in maize was reduced by 77% after two years of soybean and 75% after two years of cowpea. In addition, maize grain yield increased by 87% after two years of soybean and 66% after two years of cowpea. These indicate the ability of these grain legumes to reduce *Striga* infestation and increase grain yield. On heavily infested *Striga* fields, more frequent cultivation of grain legumes before the introduction of cereals may be necessary.

Striga germination may also be suppressed by the nitrogen fixed by the legumes. However, this does not appear to be likely because the legumes do not release much nitrogen into the soil during their growth (van der Heide *et al.*, 1985; Carsky *et al.*, 1994; Sanginga *et al.*, 2002). Usually large amounts of nitrogen are required to reduce *Striga* density (Mumera and Below, 1993). However, improved growth and vigor due to N may help the maize crop to overcome *Striga* attacks. Although there were significant reductions in *Striga* infestation and maize yield loss due to *Striga*, *Striga* infestation and damage ratings in the continuously cropped maize was lower than that reported for *Striga*-susceptible maize in the savanna (A. Menkir, personal communication). This is because the maize variety used was *Striga*-resistant/tolerant. It is presently the most resistant maize against *Striga* in the West African savanna. Its continuous cultivation may lead to reduction in the *Striga* seed bank.

Although the above benefits of legume rotation in *Striga* control may be unrelated to N supply, our data show that legume-maize rotation increased N supply to subsequent maize. Although all treatments received equal amounts of fertilizer N (100 kg N/ha), total N in previous legume plots was more than in continuous maize plots. This additional N supply coupled with other rotational effects may have increased the yield of subsequent maize. Carsky *et al.* (1997) established N supply as the major influence of soybean on subsequent maize and found a reduction in maize yield response to inorganic N following soybean. The increases in N supply in previous cowpea and soybean treatments and yield of subsequent maize was probably due to additional N fixed and left in the soil for the subsequent maize crop. Sanginga *et al.* (2002) reported a nodulating soybean to fix about 103 kg N/ha of its total N with an estimated net N balance input from fixation following grain harvest of 43 kg N/ha. They also reported that maize growing after this soybean had 1.2 to 2.3-fold increase in yield compared to the maize control. In the present study, N contents of roots and litter of the previous soybean and maize crops were not determined, so the two effects could not be quantified.

5 Conclusion

It can be concluded from our findings that:

(1) Continuous cultivation of sole maize will increase *Striga* infestation. However, if the maize grown is resistant to *Striga*, there may be some reduction in field infestation due to depletion of *Striga* seed bank.

(2) Rotation of cereals and grain legumes such as soybean and cowpea can reduce *Striga* infestation and increase grain yield. The reduction of *Striga* infestation and maize yield increases will be higher if the legumes are cultivated for over one cropping seasons before maize is introduced.

(3) Although, maize-cowpea intercropping reduced maize grain yield due to competition effects, the higher crop value of cowpea component makes the system profitable and farmers should be encouraged to continue practicing it.

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Wirkungen eines polymeren Bodenverbesserers auf die Ertragsbildung von Hirse unter ariden Bedingungen

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Zusammenfassung

Wasser ist in (semi)ariden Gebieten der entscheidende begrenzende Faktor in der Pflanzenproduktion. Unter dem Aspekt einer erhoehten Wasserspeicherung wurde die Wirkung einer Polymer-Gabe von 0 bzw. 0.3 % (G/G) zu drei Böden (leicht/mittel/schwer) bei drei Bewässerungsfrequenzen (4-, 8-, und 12-tägig) auf die Ertragsbildung von Hirse (*Panicum antidotale* Retz), die Wasserspeicherung und N-Auswaschung im Freiland (nordwestlich von Teheran) geprüft.

Vierzig Tage (d) nach Versuchsbeginn sank die Überlebensrate der Pflanzen, insbesondere auf leichtem Boden und bei geringer Bewässerungsfrequenz progressiv. Polymer-Zusatz und eine erhöhte Bewaesserungsfrequenz zeitigten bei allen Pflanzenmerkmalen klare positive Wirkungen, wobei z. T. deutliche Interaktionen, auch mit den Boeden bestanden. Auf allen Böden, insbesondere aber auf mittlerem Boden, welcher die Rispen- und Biomassebildung begünstigte, war der Effekt des Polymerzusatzes bei geringer bzw. mittlerer Bewässerungsfrequenz am stärksten ausgepraegt. Die Wechselwirkungen zwischen den Versuchsfaktoren werden vor dem Hintergrund einer durch Polymerzusatz erhoehten Wasserspeicherung und verminderten N-Auswaschung diskutiert.

Stichwörter: Polymer, Wasserspeicherung, Bewässerungsfrequenz, Bodenarten, Ertragsbildung von Hirse, Uberlebensrate, N-Auswaschung

1 Einleitung

Wasser stellt ein Hauptproblemfaktor in der Pflanzenproduktion arider und semiarider Regionen dar. Nicht nur die natürliche Wasserknappheit begrenzt die Standortproduktivität, sondern auch ungünstige physikalische Bodeneigenschaften, wie geringe Infiltration, sowie Wasserspeicherung und -nachlieferung. Neben der Anwendung von Gründüngung, Mulchen oder anderer organischer Dünger, die zur Milderung dieser Probleme beitragen können, ist in den letzten Jahren auch der Einsatz von polymeren Bodenverbesserern getestet worden. Hierzu zählen z.B. Perlit, Igeta, Hydroplus und andere Superabsorbenten bzw. Polymere. Diese Mittel können bei Kontakt mit Was-

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ser das 300 bis 500-fache ihres Volumens an Wasser absorbieren und es wieder an die Pflanzen abgeben. Neben dieser Wasserabsorption, die zu einer besseren Pflanzen- und Wurzelentwicklung führen kann, ist auch eine verminderte Nährstoffauswaschung aus dem Boden durch Polymere zu erwarten, wobei die Wirksamkeit im Boden mit bis ca. 5 Jahren angegeben wird (*Super AB, A-100*, Iran Polymer Institute). Polymere Bodenverbesserer können bei Neuanpflanzungen von Baumkulturen auf leichteren Böden trockener Klimata positive Effekte erzielen, wie Dosiseffekte von Polymerzusätzen zum Boden auf die Überlebensrate von Kiefernsämlingen (*Pinus halepensis*) in Versuchen von HÜTTERMANN *et al.* (1997) belegen. In Versuchen mit *Populus euphratica* auf salzhaltigem Boden (Hüttermann et al. 1997) liessen Polymer-Behandlungen mit 0 % bis 0.6 % nach 7 und nach 60 Tagen ebenfalls abgestufte, deutliche Verbesserungen von Wachstum und Überlebensrate erkennen.

Aus anderen Bewässerungsversuchen von HÜTTERMANN *et al.* (1999) auf leichten Wüstenböden geht hervor, dass die durch Polymere gesteigerte Wasserspeicherung einen entscheidenden Einfluss auf das Überleben der Pflanzen ausübten. Darüber hinaus konnte in diesen Versuchen, wie auch in denen von DEHGAN *et al.* (1994), eine erhöhte Wurzelmasse bei Polymerzugaben beobachtet werden. In einem weiteren Bericht über Polymerversuche in Südafrika wird mitgeteilt, dass durch die Verwendung von Polymeren im Boden nicht nur die Sterblichkeitsrate von Eukalyptuspflanzen deutlich reduziert wurde, sondern auch die Bewässerungskosten abnahmen (ANONYMOUS, 1998).

Ziel dieser Untersuchung war es, zu prüfen, inwieweit auch an annuellen Nutzpflanzen unter den ariden Bedingungen des Irans positive Wirkungen von Polymerzugaben nachgewiesen werden können. Darüber hinaus sollten mögliche Wechselwirkungen mit Bewässerungsmassnahmen bzw. mit unterschiedlichen Wasserspeicherkapazitäten von Böden untersucht werden. Als annuelle Pflanze wurde hier Futterhirse (*Panicum antidotale* Retz.) ausgewählt, weil diese Pflanze neben Viehfutter auch als Schutz gegen Winderosionen in Trocken- bzw. Wüstengebieten eingesetzt werden kann.

2 Material und Methoden

Die Untersuchungen wurden in einem Gefässversuch im Freiland während des Jahres 2000 am Forschungsinstitut für Wald und Weidewirtschaft (16 km nord-östlich von Teheran, 1300 m ü. NN) durchgeführt. Die mittleren jährlichen Niederschläge betragen dort ca. 230 mm mit Schwerpunkten im Frühjahr und im Spätherbst, so dass während der Versuchsmonate im Sommer weniger als 10 mm Regen fielen. Während des Versuchszeitraums betrug die monatliche Verdunstung ca. 170 mm und die mittleren Temperaturen lagen bei 21°C. Das Saatgut der Futterhirse (*Panicum antidotale* Retz.) wurde aus der Genbank des Forschungsinstituts (für Wald- und Weidewirtschaft) bezogen und zuvor auf seine Keimfähigkeit geprüft. Es wurden vier Körner pro Gefäss ausgesät und später auf eine Pflanze pro Topf ausgedünnt. Die Gefässe wurden jeweils mit 4 kg Boden unterschiedlicher Herkunft und Art (leicht, mittel und schwer, s. Tab. 1) befüllt. Den Böden wurde eine Dosis von 0 bzw. 0,3 % (G/G) des Polymers *Super AB, A-100* (Iran Polymer Institute) zugesetzt, welches den Verhältnissen in anderen Untersuchungen entsprach (WANG und GREGG, 1990; BOWMAN *et al.*, 1990; DEHGAN *et al.*, 1994; HÜTTER-

MANN *et al.*, 1997, 1999). Das verwendete Polymer bestand aus Polyacrylsäure mit einer Körnung von 0,05 - 0,15 mm, einer Dichte von 1,4 - 1,5 g/cm^3 und hatte einen pH-Wert von 6 - 7 im wassergesättigten Zustand, welcher bei 203 g/g Polymer erreicht war. Die Bewässerung wurde mit 3 unterschiedlichen Frequenzen, alle 4, 8 oder 12 Tage vorgenommen, wobei zu jedem Bewässerungstermin den Gefässen entsprechend des Gewichts Wasser bis zum leichten Überschreiten der Feldkapazität zugegeben wurde.

Der Versuch war als split-split-plot design angelegt mit 3 Bewässerungsfrequenzen (3 main plots), die jeweils die 3 Bodenarten (3 split plots) beinhalteten, die wiederum jeweils in den unbehandelten und polymer-behandelten Boden (2 subsplit plots) unterteilt waren. Der Versuch wurde mit 4 Wiederholungen durchgeführt.

Die Düngermengen fur N-P-K entsprachen den Empfehlungen von FINCK (1992) (berechnet über 80 000 Pflanzen/ha). Eine P- und K-Düngung (35 kg P/ha, 200 kg K /ha) wurde in Form von Triplesuperphosphat und Kaliumsulfat vorgenommen und dem Boden vor der Saat beigemischt. Die Stickstoffdüngung wurde mit ca. 100 kg/ha N dem Boden als wässrige Lösung in Form von Ammoniumnitrat zugeführt..Ein Viertel der N -Menge wurde im Sämlingsstadium, der Rest zur Blüte verabreicht. Die jeweils nach der N-Applikation erfolgenden 2 Bewässerungen waren derart bemessen, dass jeweils ca. 50-80 ml Sickerung erzeugt wurde, um den Einfluss des Bodenverbessers auf die potentielle N-Auswaschung ermitteln zu können.

Die Bodenkennwerte (Tab. 1) wurden im Labor des Research Institute of Forest & Rangelands i. W. nach Standardmethoden ermittelt (elektrische Leitfähigkeit und pH-Wert im Sättigungs-extrakt elektrometrisch, Stickstoff nach Kjeldahl mit Aufschluss nach ROWELL (1994), Carbonatgehalt nach SCHLICHTING *et al.* (1995), Phosphat nach Olsen gemäß SCHINNER *et al.* (1991), Kalium mit 1N Ammoniumacetat nach COTTENIE (1980), organischer Kohlenstoff nach Walkley und Black gemäß BARUAH und BARTHAKUR (1997), KAK mit Ammonium bzw. Natrium flammenphotometrisch und Korngrössenverteilung hydrometrisch).

Tabelle 1: Kenndaten der unbehandelten Versuchsböden.

Bodenart *(% Ton/Schluff/Sand)*	*pH*	*EC* *[dS m^{-1}]*	P *[mg kg^{-1}]*	K *[cmol kg^{-1}]*	*KAK* *[%]*	*WGS** *[%]*	N_t *[%]*	*OC* *[%]*	$CaCO_3$ *[%]*
leicht (2/2/96)	7.42	1.65	0.10	5.7	4.1	26.7	0.029	0.21	5.33
mittel (20/50/30)	7.78	3.51	0.25	27.1	8.2	35.9	0.045	0.40	6.67
schwer (30/38/32)	7.33	2.23	0.14	12.8	8.7	40.4	0.056	0.51	9.33

* Wassergehalt bei Sättigung [% G/G], ermittelt aus Gewicht im gesättigten und stark luftgetrockneten Boden.

An den Pflanzen wurde die phänologische Entwicklung (Feldaufgang, Schoss- und Blühbeginn, absolute Pflanzenanzahlen) jeweils an verschiedenen Tagen bonitiert und später die Überlebensrate regelmässig erfasst. Zur Varianzanalyse der Überlebensrate wurden die Daten zunächst nach der Formel $X = \sqrt{x + 0.5}$ transformiert und anschliessend analysiert, wobei x den Wert 0 für abgestorbene und 1 für lebende Pflanzen annehmen konnte. Bei der Probenahme einzelner Pflanzen wurde die Trockenmasse (105°C), die Rispenanzahl und die Pflanzenhöhe ermittelt. Das Datenmaterial wurde einer Varianzanalyse unterzogen und bei Vorliegen von signifikanten Effekten wurden Mittelwertsvergleiche mittels des Duncan-Tests durchgeführt. Die Auswertung erfolgte mit dem Statistikprogramm MSTAT.

3 Ergebnisse

Die phänologische Entwicklung der Futterhirse war gekennzeichnet durch Aufgang am 7.-9. Tag nach der Saat (TnS), Schossbeginn zwischen dem 31.-38. TnS und Blühbeginn zwischen dem 52.-55. TnS. Die drei Versuchsfaktoren zeitigten bei allen fünf Pflanzenmerkmalen (Tab. 2) signifikante Hauptwirkungen, aber auch Wechselwirkungen, insbesondere zwischen der Bewässerung (A) und dem Boden (B). Bezüglich der Hauptwirkungen (Tab. 3) erwies sich der mittlere Boden generell als das günstigste Substrat und eine Verringerung der Bewässerungsfrequenz senkte sowohl Überlebensrate, die Pflanzenhöhe, Rispenanzahl und Trockenmasse der Hirse stufenweise; hierbei war die Reduktion jeweils auf dem leichten Boden relativ am stärksten ausgeprägt. Ein positiver Effekt des polymeren Bodenverbesserers auf die Überlebensrate der Hirse (Abb. 1) prägte sich zunehmend ab dem 35 TnS aus, und erhöhte die Rate zur Reife absolut um 10 %, was im wesentlichen auf der Wirkung bei leichtem Boden mit 4- und 8-tägiger Bewässerung und bei mittlerem Boden bei 12-tägiger Bewässerung beruhte (vergl. Tab. 3).

Tabelle 2: Varianzanalysen zum Einfluss der Versuchsfaktoren Bewässerung (A), Boden (B) und Polymerzusatz (C) auf verschiedene Merkmale.

		F-Werte				
Quelle	*Freiheitsgrade*	*Überlebensrate*†	*Rispenzahl*	*Pflanzenhöhe*	*Trockenmasse*	N *im Dränwasser*
A	2 (1)‡	10.5**	18.3***	13.8***	47.6**	32.8**
B	2	33.4**	72.7***	37.1***	75.1**	14.3**
AB	4	7.0**	5.8**	1.4^{ns}	4.9**	5.9*
Error	27 (6)‡	–	–	–	–	–
C	1	4.8*	15.1***	13.1**	67.3**	10.2*
AC	2	0.3^{ns}	0.6^{ns}	0.01^{ns}	0.5^{ns}	0.6^{ns}
BC	2	2.1^{ns}	1.6^{ns}	1.0^{ns}	3.5*	0.9^{ns}
ABC	4	1.7^{ns}	4.4**	3.6*	3.3*	0.1^{ns}
Error	27 (6)‡	–	–	–	–	–
Total	71 (23)‡	–	–	–	–	–

† Freiheitsgrade ( ) für N im Dränwasser; ‡ transformierte Daten
*/**: signifikant bei p = 0.05 bzw. 0.01, ^{ns}: not significant

Das Zusammenwirken der drei Versuchsfaktoren auf die wichtigen Ertragsmerkmale Rispenanzahl und Trockenmasse (Abb. 2 und 3) war sehr ähnlich, wobei ein positiver Polymer-Effekt sich praktisch auf allen Boden×Bewässerung-Kombinationen abzeichne-

Tabelle 3: Haupt- und Wechselwirkungen[1] von Bewässerung (A) und Boden (B) auf die diversen Merkmale der Rispenhirse am Versuchsende.

Merkmal	*Boden*	*Bewässerungsfrequenz* *4-tätig*	*8-tägig*	*12-tägig*	*Boden (B)*
Überlebensrate [%][2]	leicht	88.8 ^{a}	55.0 ^{b}	10.0 ^{c}	51.3$^{\beta}$
	mittel	100.0 ^{a}	100.0 ^{a}	88.8 ^{a}	96.3$^{\alpha}$
	schwer	100.0 ^{a}	100.0 ^{a}	100.0 ^{a}	100.0$^{\alpha}$
	Bewässerung (A)	96.3$^{\alpha}$	85.0$^{\alpha}$	66.3$^{\beta}$	–
Pflanzenhöhe [cm]	leicht	Keine signifikante Wechselwirkung (ns) zwischen A×B			17.2$^{\beta}$
	mittel				46.6$^{\alpha}$
	schwer				54.3$^{\alpha}$
	Bewässerung (A)	52.5$^{\alpha}$	36.7$^{\beta}$	29.0$^{\beta}$	–
Rispenanzahl je Pflanze	leicht	1.1 ^{d}	0.3 ^{e}	0.0 ^{e}	0.5$^{\gamma}$
	mittel	9.3 ^{a}	5.4 ^{b}	3.3 ^{c}	6.0$^{\alpha}$
	schwer	2.6 ^{cd}	1.4 ^{cde}	1.4 ^{cde}	1.8$^{\beta}$
	Bewässerung (A)	4.3$^{\alpha}$	2.4$^{\beta}$	1.6$^{\beta}$	–
Trockenmasse je Pflanze [g]	leicht	2.20 ^{d}	0.68 ^{e}	0.00 ^{e}	0.96$^{\gamma}$
	mittel	6.75 ^{a}	3.74 ^{b}	2.53 ^{cd}	4.34$^{\alpha}$
	schwer	3.48 ^{bc}	2.35 ^{d}	2.09 ^{d}	2.64$^{\beta}$
	Bewässerung (A)	4.14$^{\alpha}$	2.25$^{\beta}$	1.54$^{\gamma}$	–

[1]: unterschiedliche Buchstaben zeigen signifikante Hauptwirkungen A bzw. B (α, β, γ) bzw. Wechselwirkungen A × B ($a - e$) an

[2]: transformierte Daten

te. Ausnahme bildeten die Kombination L12, wo alle Pflanzen abgestorben waren, und M4, bei der ohne Polymergaben höchste Rispenanzahlen und Trockenmassen erreicht wurden. Signifikant war der Polymer-Effekt bei den Kombinationen (S8), S4, M12 und M8, bei welchen halbwegs passable Wachstumsbedingungen (s. u.) auch ohne Polymergaben noch eine mäßige Ausprägung zu liessen. Dies zeigt sich auch an der zunehmenden Polymer-Wirksamkeit von leichten, über den schweren, zum mittleren Boden (Tab. 4).

Effekte der polymeren Bodenverbesserer auf die Pflanzen könnten unmittelbar über die erhöhte Wasserspeicherfähigkeit der Böden, aber auch indirekt über eine verminderte Nährstoffauswaschung bei überschüssigem Regen wirksam werden. Deshalb wurden die Feldkapazität und N-Menge in Sickerwasser untersucht. Der Wassergehalt bei Feldka-

Abbildung 1: Wirkung des polymeren Bodenverbesserers auf die Überlebensrate von Hirse.

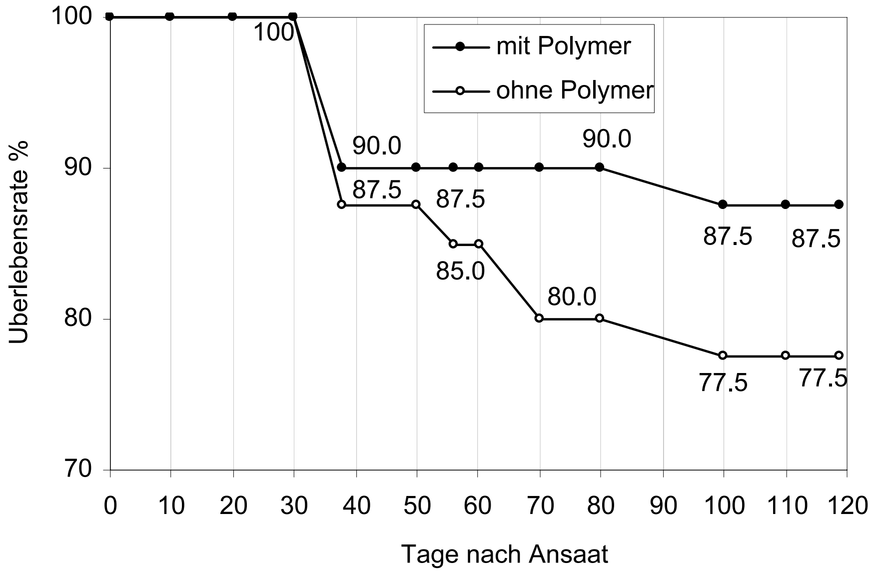

Abbildung 2: Wechselwirkungen von Polymerzusatz, Bewässerung und Boden auf die Rispenanzahl von Hirsepflanzen am Versuchsende. (Bewässerung: 12/8/4 =12-, 8- und 4-tägig; Boden: L=leicht, M=mittel, S=schwer; gleiche Buchstaben bedeuten keinen signifikanten Unterschied bei $p<0.05$).

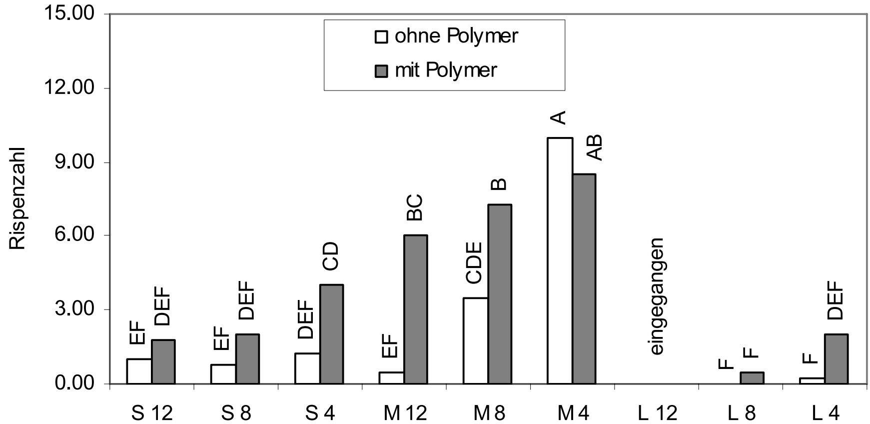

Abbildung 3: Wechselwirkungen von Polymerzusatz, Bewässerung und Boden auf die Trockenmassenbildung (g) von Hirsepflanzen am Versuchsende. (Bewässerung: 12/8/4 =12-, 8- und 4-tägig; Boden: L=leicht, M=mittel, S=schwer; gleiche Buchstaben bedeuten keinen signifikanten Unterschied bei p<0.05)

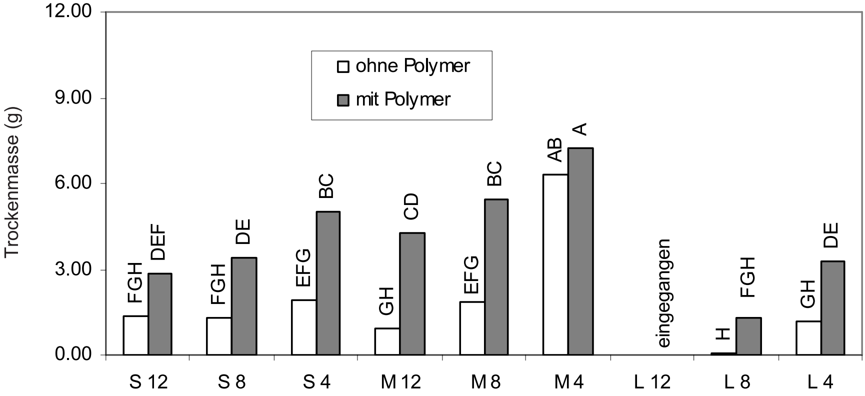

Tabelle 4: Wechselwirkung[1] zwischen Boden (B) und Polymerzusatz (C) auf die Trockenmasse von Hirse (g/Pflanze) am Versuchsende.

Bodenart	*Polymerzusatz*	
	ohne	*mit*
leicht	0.42 ^{d}	1.51 ^{c}
mittel	3.03 ^{b}	5.64 ^{a}
schwer	1.51 ^{c}	3.77 ^{b}

[1]: unterschiedliche Buchstaben zeigen signifikante Unterschiede zwischen Mittelwerten an.

pazität erhöhte sich durch die Polymere um 15 % (Tab. 5). Hinsichtlich der N-Menge im Sickerwasser (Tab. 6) ergaben sich als Hauptwirkungen eine Zunahme von der 4- zur 8-tägigen Bewässerung (A) bzw. von leichten zum schweren Boden (B) und eine Reduktion durch den Polymerzusatz (C). Zwischen Boden (B) und Bewässerung (A) bestand eine Wechselwirkung derart, dass die 4-tägige Bewässerung zwar generell niedrige N-Werte im Dränwasser der 3 Böden als die 8-tägige Bewässerung hervorrief, dies aber bei mittlerem Boden nur tendenziell erkennbar war.

Tabelle 5: Hauptwirkungen[1] von Polymerzusatz (C) und Boden (B) auf den Bodenwassergehalt bei Sättigung[2] [% G/G]

C Polymerzusatz		*B Boden*		
ohne	*mit*	*leicht*	*mittel*	*schwer*
34.3 $^{\alpha}$	49.1 $^{\beta}$	30.5 $^{\alpha}$	44.3 $^{\beta}$	50.5 $^{\gamma}$

[1]: B×C $n.s.$; unterschiedliche Buchstaben α, β, γ indizieren signifikante Mittelwertunterschiede.
[2]: aus Gewichten bei Wassersättigung und stark luftgetrockneten Böden ermittelt

Tabelle 6: Wechselwirkung zwischen Boden (B), Bewässerung (A)[1] bzw. Polymerzusatz (C) hinsichtlich den N-Konzentrationen im Dränwasser [mg N/l], an 2 Terminen nach N-Gabe ohne Berücksichtigung von 12-tägiger Beweasserung (s.Text).

Boden B	*Bewässerung A*		*Polymerzusatz C*		*Mittel B*
	4-tägig	*8-tägig*	*ohne*	*mit*	
leicht	295 ^{c}	766 ^{b}	Keine signifikante Wirkung B×C		531 $^{\beta}$
mittel	572 ^{bc}	664 ^{b}			618 $^{\beta}$
schwer	631 ^{b}	1348 ^{a}			990 $^{\alpha}$
Mittel A/C	500 ^{a}	926 ^{b}	884 $^{\alpha}$	542 $^{\beta}$	–

[1]: B×A signifikant; unterschiedliche Buchstaben zeigen Hauptwirkumgen A,B bzw. C (α, β, γ) bzw. Wechselwirkungen A×B ($a - e$)

4 Diskussion

Die phänologischen Beobachtungen zeigten, dass die Entwicklung der Futterhirse durch eine Zunahme der Bewässerungshäufigkeit bzw. durch die Polymerzugabe begünstigt war. Dies lässt sich wahrscheinlich auf bessere Wachstumsbedingungen zuruckführen und stimmt überein mit einer schnelleren phänologischen Entwicklung und einem besseren Wachstum verschiedener Gemüse- und Zierpflanzen in Folge von Polymerzugabe zum Boden in Untersuchungen von King *et al.* (1973); Ferrazza (1974); Bearce und McCollum (1977) (zitiert in Gehring und Lewis III (1980)). Verbesserte Wachstumsbedingungen spiegeln sich auch in den Überlebensraten wieder, welches an den Sämlingen von *Pinus halepensis* (Hüttermann *et al.*, 1997) durch Polymerzusatz von 0, 0,2 bzw. 0,4 % zum Boden bereits 17 TnS von 38 auf 50 bzw. 100 % festgestellt werden konnte. Auch der Anteil lebender Pflanzen von *Populus euphratica* konnte durch Zusatz von 0,6 % Polymer zu gips- und salzhaltigem Boden nach 60tägigem Wachstum von 46 auf 90 % gefördert werden (Hüttermann *et al.*, 1997). Diese Ergebnisse stimmen mit der zwischen dem 40. und 100. TnS zunehmenden Steigerung der Überlebensrate von Futterhirse durch Polymere überein, welche allgemein von einer Zunahme der Rispenanzahl, Höhe und TM je Pflanze begleitet war. Grundsätzlich können diese Wirkungen an Futterhirse auf eine verbesserte Wasserspeicherung zurückgeführt werden, wie dies analog von Gehring und Lewis III (1980) und Weaver *et al.* (1977) beschrieben wurde. Auch in anderen Arbeiten wird eine verbesserte Wasserspeicherung aufgrund von Polymeren als Ursache für ein verlängertes Überleben von Mais und Bohnen (Bakass *et al.*, 2002) und für eine bessere Turgeszenz von Erdnuss (Mohana Raju *et al.*, 2002) bei knappen Wasserangebot angesehen.

Um die Wechselwirkungen zwischen Polymergabe und den Faktoren Boden bzw. Bewässerung zu bewerten, ist es notwendig zunächst die Wechselwirkung Boden-Bewässerung zu betrachten. Auf mittlerem Boden (und eingeschränkt auch bei leichtem) erhöhte eine zunehmende Bewässerungsfrequenz die Rispenanzahl und Trockenmasse von Futterhirse stufenweise, was auf Wassermangel als begrenzender Faktor für das Wachstum hinweist. Bei dem schweren Boden hatte die Bewässerung keinen bzw. nur einen schwachen Effekt. Hieraus ist zu schlussfolgern, dass Wassermangel zumindest nicht der einzige begrenzende Faktor war. Da der schwere Boden sich von mittleren nur durch einen höheren Ton- zulasten des Schluffgehaltes unterschied, dürfte dessen nutzbare Feldkapazität - trotz des höheren Wassergehalts bei Sättigung - aufgrund eines erheblich höheren Totwassergehaltes etwas geringer, aber besonders der Grobporenanteil deutlich geringer sein (Schachtschabel *et al.*, 1989). Letzteres dürfte eine schlechte Belüftung bedingen und neben geringerer P- und K-Verfügbarkeit Ursache für eine verminderte Rispen- und TM-Bildung bei Futterhirse auf dem schweren im Vergleich zum mittleren Boden sein. Insofern ist davon auszugehen, dass bei höherer Bewässerungsfreqünz die schlechte Belüftung des schweren Bodens durch Verschlämmung der Bodenoberfläche und Stauwasser noch verstärkt wurde und somit die positive Wirkung einer besseren Wasserversorgung abmilderte bzw. überdeckte.

Allgemein war die günstige Wirkung der **Polymergabe** in Verbindung mit den verschiedenen **Boden-Bewässerungskombinationen** bezüglich der Rispen- und TM-Bildung sehr ähnlich. Auf **mittlerem Boden** war eine fördernde Wirkung der Polymergabe bei geringer und mittlerer Bewässerungsfrequenz (M 12 und M 8) deutlich erkennbar, was einer Minderung des Wassermangels zugeschrieben werden kann. Die Wirkungslosigkeit der Polymergabe bei hoher Bewässerungshäufigkeit ist mit einer an sich günstigen Wasserversorgung dieser Boden-Bewässerungskombination zu erklären. Diese Ergebnisse belegen, dass es möglich ist, die Bewässerungsfrequenz durch Polymergabe von 4- auf 8-tägig ohne Nachteil zu reduzieren. Zu ähnlicher Schlussfolgerung gelangten Hüttermann *et al.* (1997) in Versuchen an *Populus*, in denen die Bewässerung in einem längeren Intervall reduziert wurde und ein vermindertes Wachstum je nach Höhe der Polymerzugabe erst deutlich verzögert eintrat. Auch Experimente von Dehgan *et al.* (1994); Dehgan (1995) sowie Still (1976) weisen in die gleiche Richtung. Auf **schwerem Boden** hatte die Bewässerungsfrequenz kaum einen Effekt auf die Rispenanzahl und TM, dennoch wirkten Polymergaben bei S 12, S 8 und S 4 in ähnlichem Umfang (tendenziell bzw. signifikant, Abb. 2 und 3). Dies könnte auf einer Minderung von Verschlämmung und Stauwasser infolge eines durch Polymere verbesserten, stabileren Bodengefüges beruhen.

Auf dem **leichten Boden**, einem humusarmen Sand, war die Wasserspeicherung allgemein so gering, so dass ohne polymere Bodenverbesserer nur bei hoher Bewässerungsfrequenz eine sehr geringe Rispen- und TM-Bildung möglich war, welche mit Polymergabe schon bei mittlerer Frequenz erreicht wurde und bei hoher Frequenz noch deutlich übertroffen wurde. Auf sehr leichtem Boden ist allerdings eine angemessene Hirseproduktivität nur bei hoher Bewässerungsfrequenz und Polymereinsatz zu erzielen. In die gleiche Richtung weisen Untersuchungen von Geesing und Schmidhalter (2004), in denen eine signifikante Erhöhung der Trockenmasse bei Weizen nur erzielt wurde, wenn durch die Polymere ein Wassermangel vermieden wurde.

Insgesamt zeigen die Untersuchungen, dass Polymereinsatz auf mittleren und leichten Böden die Wasserversorgung und die Produktivität von annuellen Pflanzen wie Futterhirse verbessern kann, und bei mittlerem Boden die notwendige Bewässerungsfrequenz und damit auch Arbeit sowie Kosten gesenkt werden können. Dies bestätigen Untersuchungen von Sivapalan (2001a), anhand steigender Erträge von Sojabohnen aufgrund zunehmender Polymergaben bzw. gleicher Erträge, wenn bei höherer Polymerzugabe die Bewässerungsfrequenz erniedrigt wurde.

In einer weiteren Arbeit belegte Sivapalan (2001b) auf leichtem Boden eine verbesserte Wasserspeicherung durch Polymerzusatz, welche in unserem Versuch auf allen drei Böden auch die N-Auswaschung verringerte. Dabei ist die unerwartete höhere N -Auswaschung bei 8-tägiger im Vergleich zur 4-tägigen Bewässerung vermutlich auf die geringere Biomassebildung (Tab. 4) bzw. damit auch verringerter N-Aufnahme durch die Pflanzen nach der zweiten N-Gabe zur Blüte zurückzuführen. Die Versuche von Syvertsen und Dunlop (2004) weisen auch darauf hin, dass durch Polymerzusatz zu einem Sandboden die N-Aufnahme von Citrusssämlingen zunahm und darüber hinaus auch eine N-Auswaschung dort verhindert wurde.

Es bleibt zu prüfen, ob die allgemeine Förderung der Pflanzen durch Polymerzugabe auf schweren Böden (s u L) eventuell auf einer Strukturverbesserung des Bodens im Sinne einer besseren Belüftung beruhte.

Effects of a Polymer for Soil Amendation on Yield Formation of Millet under Arid Conditions

Summary

In arid and semiarid regions water is one of the main limiting factor for plant production. With regard to advantages of an improved water-holding capacity in such regions, we investigated the effects of polymer addition (0,3 % w/w) to three soils (light, medium and heavy) and of three irrigation frequencies (every 4, 8 or 12 days) on the survival and growth of *Panicum antidotale* Retz and on nitrogen leaching under the climatic conditions of north-west Iran.

40 d after sowing survival rate of millet decreased progressively, particularly on the light soil and at a low irrigation frequency. Polymer admixtures and high irrigation frequencies provoked marked positive effects on all plant traits with significant interactions with soils. On all soils, but particularly on the medium soil which favored panicle and biomass production, the effects of polymers were most pronounced at low and medium irrigation frequencies. The interactions are discussed on the background of an improved water-holding capacity, a better soil aeration, and a reduced leaching of nitrogen due to the polymer admixture.

Keywords: polymer admixture, water-holding capacity, irrigation frequency, millet, Panicum antidotale, nitrogen leaching, survival rate

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Variation in the Response of Seed and Embryonic Axes to Incubation Temperature Gradients during Seed Treatments in Pearl Millet and Sorghum

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Abstract

Incubation temperature during the presowing soaking of seeds plays a significant role in determining the rate and characteristics of post-treatment germination. Three experiments were conducted on sorghum (*Sorghum bicolor* L Moench) and pearl millet (*Pennisetum glaucum* L. R. Br.) genotypes to determine the influence of constant, alternating, ascending and descending temperature regimes on germination characteristics of seeds after treatment. Incubation temperatures ranging from 10 to 35°C were applied as well as alternating the magnitude and range of day/night temperatures. A third experiment tested a 3-day temperature gradient and its impact on germination and seedling characteristics. All three incubation temperature regimes were combined with various hormonal and mineral seed soaking treatments to test for possible interactive effects. Temperature did not affect the final germination percentage of seeds but influenced the germination rate. Constant temperatures of 20 or 25°C induced higher germinative capacity than alternating or constant temperatures of higher or lower magnitude. Increasing the variance in day/night temperature reduced the rate of germination. Incubating seeds during soaking treatments at a constant 20°C for 3 days yielded better germination characteristics than a thermal gradient of 25/20/15°C. An 8g $l^{-1}NaCl$ treatment induced greater plumule (shoot) growth than non-treated counterparts and treating seeds with GA_3 or salts improved germination characteristics and synchrony of treated seed lots.

Keywords: seed treatments, treatment temperature, germination, plumule, radicle

1 Introduction

Emergence and establishment of rainfed sorghum and pearl millet may not always be completely successful since, after imbibition, any water shortage delays emergence, exposing the seeds to stress (Al-Mudaris, 1998b; Kader, 2001; Kader and Jutzi, 2001). Therefore, there has recently been an upsurge of interest in the use of presowing seed treatments involving full or partial hydration of seeds, which may improve emergence and subsequent establishment (Gurushinghe *et al.*, 1999; Powell *et al.*, 2000; Gallardo *et al.*, 2001; Harris, 2001; Araus *et al.*, 2002; Kader and Jutzi, 2002).

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Such treatments include the soaking of seeds in high osmotic potential solutions for various periods of time (Heydecker, 1978; Heydecker and Gibbins, 1978; Brocklehurst and Dearman, 1984; Demir and van de Venter, 1999; Gosling *et al.*, 1999; Lin and Sung, 2001). Temperature, which is an important variable in such treatments, has both qualitative and quantitative effects on subsequent germination rates of treated seeds (Heydecker *et al.*, 1973; Argerich and Bradford, 1989; Hardegree, 1994; Hampton *et al.*, 2000). Reports on the optimum incubation temperature have been inconsistent and do not lend themselves to easy interpretation. Booth (1992) imbibed seeds of *Eurotica lanata* at temperatures from 0 to 20°C in 5°C increments and found that as imbibition temperature increased from 5 to 15°C the probability of successful germination after soaking decreased. Brocklehurst and Dearman (1984) primed carrot, celery, leek and onion seeds at 15°C, whereas Rennick and Tiernan (1978) used 18°C. Other treatment temperatures have been reported ranging from 20°C for carrot (Austin *et al.*, 1969) to 25°C for pepper seed (Georghiou *et al.*, 1987) spanning a wide array of temperature gradients (Welbaum *et al.*, 1998; Pritchard *et al.*, 1999; Kolasinska *et al.*, 2000; Steinmaus *et al.*, 2000; Iannucci *et al.*, 00; Wuebker *et al.*, 2001). The priming of sorghum and pearl millet has not been well documented in the literature, and investigation of the effects of both constant and alternate priming temperature gradients is important in stress acclimation treatments (Al-Mudaris, 1998b; Glenn and Brown, 1998). The objective of the experiments reported here was to study the influence of incubation temperature during priming with various agents on subsequent germination rate of sorghum (*Sorghum bicolor* L. Moench) and pearl millet (*Pennisetum glaucum* L. R. Br.) seeds. Both constant and alternate temperature regimes were tested in addition to a sequential regime involving gradual temperature increases or decreases throughout the treatment period, thus creating a temperature gradient.

2 Materials and Methods

2.1 Constant incubation temperatures

Four seed treatments including a dry control were applied to four sorghum and pearl millet genotypes. All four accessions were obtained from the Asia Centre of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Patancheru, India. These included sorghum varieties ICSV 745 and M35-1, the pearl millet variety CZ-IC 923 and the pearl millet hybrid HHB 67. All seeds were tested following International Seed Testing Association regulations (ISTA, 1993) and revealed germination percentages of 95.7 to 99.3%, moisture content of 13.3 to 14.9% and viability (tetrazolium) of 99.7 to 100%. One thousand (1000) seed weights were 30.3, 38.9, 13.3 and 13.5g for ICSV 745, M35-1, CZ-IC 923 and HHB 67, respectively.

Seed treatments included soaking seed in 150 mg l^{-1} gibberellic acid (GA_3) (150 ppm), 150 mg l^{-1} kinetin (150 ppm), 5g KNO_3 l^{-1} (5%) or 5g l^{-1} $NaCl$ (5%) for 3 days (d). The control included dry, untreated seeds. All 4 seed treatments and the dry control were incubated during the 3-day (d) period at one of six temperatures. These were 10, 15, 20, 25, 30 or 35°C in incubation chambers in the dark (Conviron Industries, Canada). After treatment, seeds were retrieved from solutions, washed in distilled water and sown in 1-litre polystyrene trays. Two hundred (200) seeds were sown per tray between creased filter paper and each treatment combination replicated 6 times. Trays were placed in a germination cabinet set at a constant 35°C temperature in the dark to allow germination. Germination counts were taken at 24 hour (h) intervals for 10 d and from them the final germination percentage (FGP), first day of germination (FDG), mean germination time (MGT) and germination rate index (GRI) calculated. MGT and GRI were calculated following ORCHARD (1977) and BENECH ARNOLD *et al.* (1991), respectively. Data were arcsine transformed (YANG *et al.*, 1999; HOULE *et al.*, 2001) and subjected to an analysis of variance with mean separation at the 5 % level of probability using the General Linear Model of the SAS® statistical package (SAS Institute, USA) (SAS, 1989; BARRILLEAUX and GRACE, 2000). Trays were arranged in a Randomised Complete Block Design (RCBD) inside incubators and data exposed to one-way and two-way ANOVA (WEBER and ANTONIO, 1999).

2.2 Alternating incubation temperatures

A dry, untreated and a wet, water-soaked (distilled water) control were included in this experiment in addition to two sodium chloride-based ($NaCl$) treatments. These were 4 and 8g $l^{-1}NaCl$ solutions having an osmometer-measured (Wescor, Utah, USA) osmotic potential (Ψ_s) of -3.2 and -5.7 bar, respectively (circa -0.3 and -0.5 MPa, respectively).

Seeds of sorghum SPV 462, an ICRISAT variety, were either untreated (dry control), soaked in distilled water (wet control) or soaked in the $NaCl$ solutions for 3 d. Incubation temperatures during treatment included a constant 25°C regime and 3 alternate regimes. These were 25/20°C (12 h/12 h day/night), 25/15°C and 25/10°C. Treatments were conducted in the dark. After treatment, seeds were washed in distilled water and dried back at 25°C for 48 h to their original weight in a constant air flow cabinet (Heraeus Voetsch, Germany). Batches of 200 seeds were then sown in 1-liter polystyrene trays between creased filter paper. The paper was moistened with 50 ml of a polyethylene glycol solution (PEG molecular weight 10,000 Sigma Chemical, St Louis, USA) producing a drought level of -10 bar (-1 MPa). As an osmotic agent, PEG is metabolically inert and is ideal for simulating drought (SALISBURY and ROSS, 1992; SWAGEL *et al.*, 1997).

Trays were covered with transparent lids, replicated 6 times and placed in an incubator at 42/18°C (12 h/12 h day/night). Germination was scored daily for a period of 10 d and from the data the FGP, MGT and germination index (GI) were calculated (AL-MUDARIS, 1998a). GI assigns maximum weight to seeds germinating on the first day and less weight to seeds germinating thereafter (BENECH ARNOLD *et al.*, 1991). At the end of the test, 20 seedlings were randomly taken from the 20 middle creases in the filter paper and their plumules and radicles excised and weighed after drying at 80°C for 4 d in a reverse cycle oven (Conviron Industries, Canada). These produced the dry weight of plumule (DWP), dry weight of radicle (DWR) and the plumule to radicle ratio (PRR), which is the product of DWP divided by DWR. Statistical procedures were similar to the constant incubation temperature experiment.

2.3 Ascending and descending temperatures

The same batch of SPV 462 seeds was used in this test. Seeds were either untreated (dry control), soaked in 4g NaCl l-1 (4%) or soaked in 4g l^{-1} KCl (4%) for 3 d. Three temperature regimes were applied during soaking treatments as follows:

Regime 1 (R1): Seeds in soaking solutions exposed to 25°C on the first day of treatment, 20°C on the second day and 15°C on the third day.

Regime 2 (R2): Seeds in soaking solutions exposed to 15°C on the first day of treatment, 20°C on the second day and 25°C on the third day.

Regime 3 (R3): Seeds exposed to a continuos 20°C during the whole 3 d treatment period.

Seeds were retrieved from the solutions, dried as in the previous experiment and sown in batches of 200 in polystyrene trays in 6 replicates. Fifty (50) ml of the -10 bar PEG solution was applied to each tray and, thereafter, trays incubated at 39/15°C (12 h/12 h day/night) in the dark. Germination scores were taken daily for the first 10 d and the FGP, MGT and GI calculated. On the 11th day, 20 seedlings were randomly taken as in the previous experiment and their DWP, DWR and PRR recorded.

3 Results and Discussion

3.1 Constant incubation temperatures

Single factor analysis showed that soaking treatments did not have a significant effect on the FGP or GRI of sorghum or pearl millet seed (Table 1). Germination speed as reflected by the FDG and MGT was, however, significantly increased by seed treatments in comparison to controls. $\mathrm{GA_3}$ generally gave the fastest germination (Table 1).

Genotypes differed significantly in their germination characteristics (Table 1). The sorghum variety ICSV 745 gave the highest overall FGP and GRI pooled over treatments and incubation temperatures followed by the pearl millet variety CZ-IC 923, the hybrid HHB 67 and the sorghum variety M35-1. The slowest initiation and rate of germination were observed in HHB 67 as illustrated in Table 1. Incubation temperature also had a significant effect on the FGP, FDG, MGT and GRI. The 35°C incubation temperature resulted in the lowest FGP followed by 30°C, whereas the 10°C regime caused germination to initiate later and take longer time to complete. The 25°C regime was optimal in terms of this initiation and ending of germination as seen from FDG and MGT values (Table 1).

Interactive analysis of genotype$\times$temperature effects (Table 2) revealed the same trend. Thirty and 35°C reduced the FGP and germination speed was generally increased by an increase in incubation temperature. Seed treatment $\times$ genotype analysis showed no general preference of a genotype to one specific treatment (data not shown). The same applied to seed treatment$\times$incubation temperature effects, where no single treatment generally preferred a particular temperature but rather an overall effect of temperature in reducing the FGP as it rose to 35°C was detected (data not shown).

Table 1: Effect of seed treatments, genotype and incubation temperature on germination characteristics of sorghum and pearl millet.

	FGP (%)	*FDG (day)*	*MGT (day)*	*GRI (%/day)*
Seed Treatment				
Dry Control	65.8 ^{a}	3.6 ^{a}	3.8 ^{a}	15.4 ^{a}
GA_3	67.6 ^{a}	3.3 ^{b}	3.4 ^{b}	16.3 ^{a}
Kinetin				
64.2 ^{a}	3.5 ^{ab}	3.6 ^{b}	15.1 ^{a}	
KNO_3	64.1 ^{a}	3.5 ^{a}	3:6 ^{ab}	15.4 ^{a}
NaCl	63.6 ^{a}	3.5 ^{a}	3.6 ^{ab}	14.4 ^{a}
Genotype				
ICSV 745	87.0 ^{a}	3.3 ^{b}	3.4 ^{b}	22.1 ^{a}
M35-1	45.2 ^{d}	3.4 ^{b}	3.5 ^{b}	10.3 ^{d}
CZ-IC 923	66.1 ^{b}	3.5 ^{b}	3.6 ^{b}	15.6 ^{b}
HHB 67	62.0 ^{c}	3.7 ^{a}	3.8 ^{a}	13.3 ^{c}
Incubation Temp. (°C)				
10	71.3 ^{a}	3.9 ^{a}	4.0 ^{a}	14.8 ^{ab}
15	71.8 ^{a}	3.6 ^{b}	3.7 ^{b}	15.5 ^{ab}
20	70.3 ^{a}	3.4 ^{b}	3.5 ^{b}	16.0 ^{a}
25	68.2 ^{a}	3.1 ^{c}	3.2 ^{c}	17.2 ^{a}
30	58.5 ^{b}	3.4 ^{b}	3.5 ^{c}	15.2 ^{ab}
35	50.3 ^{c}	3.5 ^{b}	3.6 ^{b}	13.2 ^{b}

Means of treatment effects within columns followed by a similar letter are not significantly different at 5%. The same applies to means of genotype and incubation temperature effects. FGP: Final Germination Percentage, FDG: First Day of Germination, MGT: Mean Germination Time and GRI: Germination Rate Index.

3.2 Alternating incubation temperatures

The FGP of dry controls was significantly higher than that of either the wet control or the two NaCl treatments. However, the MGT of the dry control was also higher meaning that it germinated slower than those seeds that were soaked (Table 3). Due to the higher FGP of the dry control it attained a higher GI value at the end of the test. The dry weight of plumules of seeds treated with the 8g l^{-1} NaCl solution was significantly greater than those of all other treatments (Table 3), which did not differ from each other in this respect. The DWR and PRR did not differ amongst treatments.

Table 2: Interactive effects of genotype and incubation temperature on germination characteristics of sorghum and pearl millet.

Genotype	*Incubation Temp. (°C)*	*FGP (%)*	*FDG (day)*	*MGT (day)*	*GRI (%/day)*
ICSV 745	10	87.5 ^{ab}	4.1 ^{ab}	4.1 ^{ab}	18.7 $^{b-d}$
	15	92.5 ^{a}	3.8 $^{b-d}$	3.8 $^{b-d}$	20.9 $^{a-c}$
	20	86.0 ^{b}	3.4 $^{d-f}$	3.6 $^{d-f}$	20.9 $^{a-c}$
	25	88.0 ^{ab}	3.2 $^{e-g}$	3.3 $^{e-g}$	23.3 ^{ab}
	30	85.0 ^{b}	2.9 ^{gh}	2.9 ^{g}	24.0 ^{a}
	35	83.0 ^{bc}	2.7 ^{h}	2.8 ^{g}	24.9 ^{a}
M35-1	10	42.0 ^{gh}	4.0 $^{a-c}$	4.1 $^{a-c}$	8.1 ^{i}
	15	47.5 ^{gh}	3.6 ^{de}	3.6 ^{de}	9.2 ^{hi}
	20	51.5 ^{g}	3.5 $^{d-f}$	3.6 $^{d-f}$	11.8 $^{e-i}$
	25	48.5 $^{f-h}$	3.2 $^{e-g}$	3.2 $^{e-g}$	10.4 $^{g-i}$
	30	45.0 ^{gh}	3.5 $^{d-f}$	3.6 $^{d-f}$	11.7 $^{e-i}$
	35	37.0 ^{h}	2.9 ^{gh}	2.9 ^{g}	10.6 $^{g-i}$
CZ-IC 923	10	81.5 ^{bc}	3.8 $^{b-d}$	3.8 $^{b-d}$	17.1 ^{cd}
	15	81.5 ^{bc}	3.5 $^{d-f}$	3.5 $^{d-f}$	18.4 $^{b-d}$
	20	68.5 ^{de}	3.4 $^{e-f}$	3.5 $^{d-f}$	15.7 $^{d-f}$
	25	67.0 ^{de}	3.1 $^{e-g}$	3.2 ^{fg}	17.0 ^{cd}
	30	60.5 ^{ef}	3.2 $^{e-g}$	3.2 $^{e-g}$	16.0 $^{c-e}$
	35	38.0 ^{h}	4.1 ^{ab}	4.2 ^{ab}	9.4 ^{hi}
HHB 67	10	74.3 ^{cd}	3.8 $^{a-d}$	3.9 $^{b-d}$	15.1 $^{e-g}$
	15	66.0 ^{de}	3.7 ^{cd}	3.7 $^{c-e}$	13.7 $^{e-h}$
	20	75.5 ^{cd}	3.4 $^{d-f}$	3.5 $^{e-f}$	15.5 $^{d-f}$
	25	69.5 ^{de}	3.1 $^{e-h}$	3.1 ^{fg}	18.1 ^{cd}
	30	43.5 ^{gh}	4.3 ^{a}	4.4 ^{a}	9.1 ^{hi}
	35	43.5 ^{gh}	4.2 ^{a}	4.4 ^{a}	8.0 ^{i}

Means in columns followed by similar letters are not significantly different at 5%.

FGP: Final Germination Percentage, FDG: First Day of Germination, MGT: Mean Germination Time and GRI: Germination Rate Index.

Table 3: Effect of seed treatments and incubation temperatures on germination and seedling characteristics of sorghum SPV 462 seeds.

	FGP (%)	*MGT (day)*	*GI*	*DWP (mg)*	*DWR (mg)*	*PRR*
Seed Treatment						
Dry Ctrl.	82.8 ^{a}	4.0 ^{a}	535.4 ^{a}	1.0 ^{b}	1.5 ^{a}	0.83 ^{a}
Wet Ctrl.	61.2 ^{b}	3.5 ^{b}	432.2 ^{bc}	1.3 ^{b}	1.7 ^{a}	0.88 ^{a}
4g/l $NaCl$	58.0 ^{b}	3.3 ^{bc}	401.7 ^{c}	1.1 ^{b}	1.6 ^{a}	0.75 ^{a}
8g/l $NaCl$	53.0 ^{b}	2.9 ^{c}	486.6 ^{ab}	2.0 ^{a}	2.1 ^{a}	0.97 ^{a}
Incubation Temp. (°C)						
25	68.5 ^{a}	3.1 ^{b}	521.4 ^{a}	1.4 ^{a}	2.3 ^{a}	0.64 ^{a}
25/20	64.9 ^{a}	3.3 ^{b}	476.1 ^{ab}	1.2 ^{a}	1.5 ^{b}	0.89 ^{a}
25/15	63.0 ^{a}	3.9 ^{a}	426.0 ^{b}	1.3 ^{a}	1.5 ^{b}	0.93 ^{a}
25/10	58.5 ^{a}	3.5 ^{ab}	432.5 ^{b}	1.5 ^{a}	1.6 ^{ab}	0.97 ^{a}

Means of treatment effects within columns followed by a similar letter are not significantly different at 5%. The same applies to means of incubation temperature effects.

FGP: Final Germination Percentage , MGT: Mean Germination Time, GI: Germination Index, DWP: Dry Weight of Plumule, DWR: Dry Weight of Radicle, PRR: Plumule/Radicle Ratio, Dry Control: untreated seeds, and Wet Control: Water-soaked seeds.

Incubation temperature also did not seem to have an effect on the FGP of sorghum seeds (Table 3), but affected germination speed as seen from the MGT values. The 25°C constant temperature regime gave faster germination than the 25/15°C regime. The GI was also higher for the 25°C regime than the 25/15 or 25/10°C regimes (Table 3). Neither DWP nor PRR were affected by incubation temperature even though the DWR was higher at 25°C than at 25/20 or 25/15°C.

Interactive analysis between seed treatments and temperature regimes revealed no preference of treatments for a certain temperature but a tendency of water-soaked seeds to perform better under the 25°C regime than under others (data not shown). Otherwise, the same results as those of single factor effects were observed.

3.3 Ascending and descending temperatures

As seen from Table 4, the 4g l^{-1} KCl treatment, pooled over all three temperature regimes, yielded a significantly lower FGP than the dry control and the 4g l^{-1} $NaCl$ treatment. Again, the effect of soaking treatments was that of increasing germination speed as seen by lower MGT values in the salt soaks.

The 4g l^{-1} $NaCl$ treatment gave the best FGP×MGT relationship as it yielded the highest GI value. Seedling characteristics, represented by DWP, DWR and PRR were

Table 4: Effect of seed treatments and incubation temperature sequences on germination and seedling characteristics of sorghum SPV 462.

	FGP (%)	*MGT (day)*	*GI*	*DWP (mg)*	*DWR (mg)*	*PRR*
Seed Treatment [1]						
Dry Ctrl.	84.0 ^{a}	3.9 ^{a}	593.3 ^{b}	2.4 ^{a}	2.1 ^{a}	1.1 ^{a}
4g/l $NaCl$	84.7 ^{a}	2.9 ^{b}	678.8 ^{a}	2.6 ^{a}	2.6 ^{a}	1.0 ^{a}
4g/l KCl	78.2 ^{b}	3.3 ^{b}	593.7 ^{b}	2.8 ^{a}	2.6 ^{a}	1.0 ^{a}
Incubation Temp. (°C) [2]						
25/20/15	81.6 ^{a}	3.8 ^{a}	584.4 ^{a}	2.8 ^{a}	2.9 ^{a}	0.9 ^{b}
15/20/25	82.8 ^{a}	3.3 ^{ab}	631.4 ^{a}	2.7 ^{ab}	2.2 ^{b}	1.2 ^{a}
20	82.4 ^{a}	3.0 ^{b}	651.1 ^{a}	2.3 ^{b}	2.1 ^{b}	1.0 ^{ab}

[1]: Means of treatment effects within columns followed by similar letters are not significantly different at 5%. The same applies to means of temperature effects.

[2]: Alternating temperatures indicate temperatures on days 1, 2 and 3, respectively and 20°C represents a continuos temperature for the whole 3 d period.

FGP: Final Germination Percentage , MGT: Mean Germination Time, GI: Germination Index, DWP: Dry Weight of Plumule, DWR: Dry Weight of Radicle and PRR: Plumule/Radicle Ratio.

not affected by soaking treatments. The sequence of incubation temperature did not play a role in the FGP of seeds, but rather in the MGT (Table 4). Seeds incubated under the 20°C constant temperature regime germinated faster than those incubated under the 25/20/15°C sequence (R1). There was no significant difference between R1, R2 and R3 in GI terms. The growth of plumules and radicles in addition to their ratio was affected by temperature regime, as 25/20/15°C gave significantly higher DWP than both 15/20/25°C and 20°C. The difference in weight between plumules and radicles in favour of the former was more pronounced at 4g l^{-1} $NaCl$ in R2 than in R1, thus yielding higher PRR values in the former (Table 5).

The general picture which emerges from the data is that the seed soaking treatments reported seem to be more efficient in increasing germination speed than its final percentage. This effect appears not to be altered by post treatment drying of the seed since the general line of effects observed in the first experiment where seeds were sown fresh was also observed in the dried-back seeds of the second and third experiments. Moreover, the three experiments included different temperature and moisture conditions. The constant temperature experiment was conducted at 35°C without inducing drought, whereas the alternating temperature experiment had a 42/18°C day/night temperature averaging 30°C on a 24 h basis. It also received a PEG-induced drought treatment of -10 bar as did the third experiment. This would tend to point to flexibility in the

Table 5: Interactive effects of seed treatments and incubation temperature sequences on germination and seedling characteristics of sorghum SPV 462 seeds.

Seed Treatment	*Incubation Temp. (° C)*[1]	*FGP (%)*	*MGT (day)*	*GI*	*DWP (mg)*	*DWR (mg)*	*PPR*
Dry Ctrl.	25/20/15	85.3 ^{b}	4.0 ^{a}	588.3 ^{d}	2.8 ^{a}	2.6 ^{bc}	1.0 $^{a-c}$
	15/20/25	84.6 ^{b}	3.9 ^{a}	598.6 ^{cd}	2.5 ^{ab}	2.0 ^{cd}	1.2 ^{ab}
	20	82.0 ^{bc}	3.7 ^{ab}	593.0 ^{d}	2.0 ^{b}	1.8 ^{d}	1.0 $^{a-c}$
4g NaCl/l	25/20/15	82.3 ^{bc}	3.6 ^{ab}	603.0 ^{cd}	2.8 ^{a}	3.3 ^{a}	0.8 ^{c}
	15/20/25	91.0 ^{a}	2.8 ^{cd}	742.3 ^{a}	3.1 ^{a}	2.3 $^{b-d}$	1.3 ^{a}
	20	81.0 ^{bc}	2.4 ^{d}	691.3 ^{ab}	2.1 ^{b}	2.1 ^{cd}	0.9 ^{bc}
4g KCl/l	25/20/15	77.3 ^{cd}	3.7 ^{ab}	559.0 ^{d}	2.8 ^{a}	2.9 ^{ab}	1.0 $^{a-c}$
	15/20/25	73.0 ^{d}	3.3 a-c	553.3 ^{d}	2.5 ^{ab}	2.5 $^{b-d}$	1.0 $^{a-c}$
	20	84.3 ^{b}	3.0 $^{b-d}$	669.0 ^{bc}	3.0 ^{a}	2.5 ^{bc}	1.1 $^{a-c}$

Means within columns followed by similar letters are not significantly different at 5%.
[1] : Alternating temperatures indicate temperatures on days 1, 2 and 3, respectively and 20°C represents a continuos temperature for the whole 3 d period.
FGP: Final Germination Percentage , MGT: Mean Germination Time, GI: Germination Index, DWP: Dry Weight of Plumule, DWR: Dry Weight of Radicle and PRR: Plumule/Radicle Ratio.

response of sorghum and pearl millet seeds to soaking treatments within the range between 27 and 35°C during germination, confirming earlier reports (Ziska and Bunce, 1993; Forcella *et al.*, 2000; Tiryaki and Andrews, 2001; Harris, 2001).

Incubation temperature during treatment, on the other hand, seems to act in another way. A constant temperature during seed soaking appears to be more favourable for post-treatment germination than an alternating regime. In the first experiment, seeds were exposed to constant temperatures ranging from 10 to 35°C. In the second experiment the 25/20, 25/15 °C and 25/10°C regimes gave a 24 h average of 22.5, 20.0 and 17.5°C, respectively. Nevertheless, the average temperature during a day in soaking seems not to be the critical point. More significant appears to be the change in temperature, be it increasing or decreasing, during treatment. This could be confirmed by the data of the third experiment. The 25/20/15 and 20°C regimes all averaged 20°C over the 3 d soaking period. This 20°C given in one constant bulk of heat units (R3), however, yielded better post-treatment results than an increasing (R1) or decreasing (R2) regime. The upper limit of temperature with which one may treat seeds of the genotypes tested is 30°C. Temperatures over 30°C (i.e 35°C in this investigation) yielded poor results. Also, some seeds were observed to germinate during treatment as early as 24 h after initial soaking at 30 and 35°C. This was most severe in pearl millet HHB 67 and less in the M35-1 sorghum variety, and confirms earlier tests (Al-Mudaris and Jutzi, 1998b,c,a, 1999a,b).

Generally, but not always significantly, a rise in incubation temperature during treatment increased post-treatment germination speed, which agrees with the data of Khan *et al.* (1980) who obtained higher germination rates at 20°C in comparison to 10 or 15°C. However, no effect on the FGP was detected. The fact that 12 h a day of temperatures 20°C or lower (i.e. 20, 15 and 10°C in the second experiment) during a 24 h cycle, or for 24 h during a 72 h cycle (R1 and R2 treatments of the third experiment) were not as effective as the constant 20°C may point to an absolute temperature preference by soaked seeds. This means that if a threshold "low" is reached, certain changes may occur within the seed that are dependent on future temperatures in a way that may be similar to certain qualitative light responses in flowering plants. Lima bean (*Phaseolus lunatus* L.) seeds imbibed at 15°C and then allowed to germinate and grow at 25°C have been shown to produce smaller seedlings (Pollock and Toole, 1966). Thus, sensitivity to chilling injury during the first 10 minutes of imbibition has been proposed (Pollock and Toole, 1966; Kester *et al.*, 1997; Al-Mudaris, 1998b; Kolasinska *et al.*, 2000; Massardo *et al.*, 2000; Gallardo *et al.*, 2001; Kader and Jutzi, 2002). Hegarty (1978) concluded that increased injury during soaking in some species at 10 or 30°C compared to 20°C is associated with greater losses of solutes from the seeds. Simon and Wiebe (1975), on the other hand, reported that the extent of leakage depends on initial water content of the seeds, being very low if embryos already have a water content of 30% or more (Ψ_s of -80 bars) before soaking. This would not apply to the seed batches used in these experiments since moisture contents of seeds were within the normal limits of circa 13-15.0 %.

Seeds in experiments 2 and 3 were dried back after treatment and it has been reported that embryos imbibed for 60 minutes, dried and returned to water again show a rapid leakage of solutes (Bewley and Black, 1978a,b). This may be one of the reasons why dry controls gave higher FGP values in experiment 2. Imbibition at a high temperature of 35°C also increases sensitivity to ethylene (Zarnstorff *et al.*, 1994) whilst at 30°C cytokinin passage from the cotyledon to the embryonic axis is affected (Eloisa Revilla *et al.*, 1988). Hassan *et al.* (1985) observed decreased auxin concentrations with time in seeds of *Anemone coronaria* and *Ranunculus asiaticus* at 8°C compared with 24°C during soaking. Chen *et al.* (1983) reported reduced germination of chickpea seeds down to 30% when soaked at 2°C compared to 95% at 20°C. This tends to point to the presence of a threshold minimum and/or maximum below or above which seeds respond through a number of physiological events.

An increase in soaking temperature affected germination speed. This is in agreement with the results of Argerich and Bradford (1989) and Hardegree (1994), who showed increases in germination rate with rises in temperature up to 25°C. Heydecker *et al.* (1973) arrived at similar conclusions, and Khan *et al.* (1978) found that osmoconditioning celery seeds at 15°C was not as effective as at 20°C in shortening the germination period. Cotton seed germination has been found to be affected by presowing imbibition temperature. McCarty (1992), studying cyclic temperature schemes, indicated that imbibing seeds at 10°C resulted in more adverse effects than imbibing at 25°C. Keeping seeds at 10°C for periods greater than 24 h reduced seedling emergence compared with keeping seeds at 10°C for 24 h then increasing substrate temperature. Increasing substrate temperature after 48 h of exposure to 10°C was found not to reverse the damaging effects of low temperatures. This tends to confirm the conclusion that 20 to 25°C is the optimal treatment temperature.

The effect of soaking treatments on the germination and early axis growth of seedlings may not be attributed to the Ψ_s of solutions, which would decrease water uptake as it drops (GURMU and NAYLOR, 1991), but rather to possible physiological or ionic effects (AL-MUDARIS, 1998b; DEWAR *et al.*, 1998; REN and KERMODE, 1999; RICHARDS *et al.*, 2001; TIRYAKI and ANDREWS, 2001). In experiment 1 the 5g l^{-1} KNO_3 solution measured -2.4 bar on the osmometer vs. -3.9 bar for 5g l^{-1} NaCl. The Ψ_s of 4g l^{-1} NaCl and 8g l^{-1} NaCl solutions in the second experiment were -3.2 and -5.7 bar, respectively and that of 4g l^{-1} KCl in experiment 3 was -2.4 bar. It follows that differences were not large in the Ψ_s between treatments and it is, thus, difficult to trace back results to this factor, which would typically arise from notable differences in Ψ_s (HADAS and RUSSO, 1974).

The greatest increase in germination speed in the constant temperature experiment was in the GA_3 treatment. The production of gibberellin is speculated to be a prerequisite for radicle emergence (BEWLEY and BLACK, 1978a; WANG *et al.*, 1998; LIN *et al.*, 1998; PEDERSEN and TOY, 2001; LJUNG *et al.*, 2001). Additionally, cell extension of plant tissue is generally held to be regulated by hormones, especially auxins and gibberellins and, since germination culminates in radicle emergence, which in most cases comprises only cell enlargement and not necessarily cell division (BEWLEY and BLACK, 1978a; DOMINGUEZ and CEJUDO, 1999; NASCIMENTO and WEST, 2000; LAHUTA *et al.*, 2000), the promotive role of GA_3 in increasing germination speed is not surprising. Additionally, on the premise that germination may involve the synthesis of specific proteins/enzymes, the possibility that GA_3 may have an effect on protein and/or RNA synthesis (BEWLEY and BLACK, 1978b) still remains open. Exogenous application of GA_3 has been reported to stimulate growth (KOZLOWSKI, 1972) and germination percentages and rates in sorghum seeds soaked for 4-6 days in 500 or 750 ppm GA_3 at 15 and 20°C (SANTIPRACHA, 1986).

KCl was not as effective as NaCl since it yielded lower FGPs in the third experiment. The observed difference may lie within the K^+ and Na^+ ions since Cl^- is common between the two compounds. Potassium is characterized by high mobility in plants at cellular, tissue or long distance transport levels (MARSCHNER, 1995) and seems essential for the synthesis of metabolites (KOZLOWSKI, 1972). Sodium is less essential than K^+ as a mineral nutrient (MARSCHNER, 1995). The 4g l^{-1} KCl and 4g l^{-1} NaCl solutions had almost the same pH values of 5.84 and 5.87, respectively, and electrical conductivity values of 7.35 and 6.92 mS cm^{-1}, respectively. Thus, other internal effects may have played a role since a relationship between potassium, magnesium and phosphate ions, and gibberellic acid is known to exist (BEWLEY and BLACK, 1978a). Influx of Na^+, Cl^- and K^+ ions into the seed may have altered the response to temperature as these have an impact on physiological triggers (KEIFFER and UNGAR, 1997; GLENN and BROWN, 1998; HOWARD and MENDELSSOHN, 1999; GAXIOLA *et al.*, 2001).

In conclusion it is recommended that ambient room temperatures of 20 to 25°C be used for the soaking treatments reported since gains through alternating temperatures were not observed. It would also be interesting to validate the effect of GA_3 on sorghum and millet seeds under other conditions and to further investigate the effects of Na^+ and K^+ in seed priming treatments.

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