Japan. Jour. Crop Sci. 50(2) : 131-142 (1981)

# Studies on the Productivity of Grain Sorghum

## V. Effect of nitrogen fertilization and water stress on the grain yield, nitrogen uptake and translocation

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Received June 18, 1980

Many experiments have been done on the effect of nitrogen fertilizer on the growth, grain yield and protein content of grain sorghum under field, pot and even water culture conditions. In these experiments, it was found that not only grain yield, but also protein content increased with application of nitrogen fertilizers[1,6,7,12,13,18]. In the report of Chugoku National Agricultural Experiment Station, Japan[21], 4 kg nitrogen with 150 kg farmyard manure per are was observed to be the usual application amounts for grain sorghum which is applied prior to planting, at 6 leaf stage and once and/or two times at panicle formation stage, boot stage and flag leaf stage. TATENO *et al.*[25] applied 4 g ammonium sulfate as pre-planting, 4 g at 6 leaf stage and 3 g at 9 leaf stage and flag leaf stage each in 1/2,000 are WAGNER's pot.

From the above experiments, we applied 6.5 g urea per 1/2,000 are WAGNER's pot as 2 g (30%) at pre-planting, 3.2 g (50%) at 6th leaf emergence stage and 1.3 g (20%) at flag leaf stage in our experiments[14,15], and later experiments[16], 6 g urea was applied as 2–2–2 g at pre-planting, 6th leaf emergence stage and heading stage respectively. In these experiments, no nitrogen deficiency occurred even in poor soil with these levels of nitrogen application. In rice plant, application of 0.5 g nitrogen is favorable and in the investigation of the effect of nitrogen application on the ripening of kernel, extra 0.2 g nitrogen is top-dressed per 1/2,000 are WAGNER's pot[19]. Comparison of the amount of nitrogen application in rice plant and grain sorghum shows that, even though grain sorghum receives higher nitrogen application than rice plant, no abnormality occurs in grain sorghum. Therefore it is necessary to determine the optimum level of nitrogen application for higher yield and protein content in grain sorghum.

On the other hand, we observed that when grain sorghum was in 10 days drought at 6th leaf emergence stage and/or passed through first wilting conditions at 12th leaf emergence stage there was an increase in grain and protein yields compared with control[14,16]. In these experiments the nitrogen was applied at 6 g per 1/2,000 are WAGNER's pot in both control and treatments. In our water culture experiments, it was observed that, with slight increase of nitrogen concentration in the cultural solution, the grain protein yields increased, but decreased under high concentration of nitrogen. Therefore, it can be said that, the increase in grain and protein yields in plants which was in a short period of drought was partially due to increasing nitrogen concentration in the soil during the drought period. Regarding the results of water culture experiments as described above, if the increase in nitrogen concentration in the soil due to drought caused increasing grain yield and protein content, with extra nitrogen application and imposition of a short period of drought, the grain and protein yields should decrease due to high concentration of nitrogen in the soil.

The objective of this study was firstly to determine the optimum level of nitrogen application necessary to obtain higher grain yield and protein content, secondly to investigate whether increasing grain and protein yields in plants which passed through a short period of drought is due to the increase in nitrogen concentration in the soil during drought period or to other factors, and finally to investigate nitrogen uptake by plant and amount of total nitrogen translocated into the grains under the different degrees of plant water stress and nitrogen application.

## Materials and Methods

Pot experiment was carried out in the Nagoya University Farm under glasshouse conditions in 1978. The seeds of grain sorghum (*Sorghum bicolor* (L.) Moench) hybrid H-726 were planted on May 15 in 1/2,000 are WAGNER's pot and then thinned to 2 plants per pot after emergence. There were 5 pots for each treatment.

The soil was fertilized with N-P-K fertilizer prior to planting using 10 g fused phosphatic fertilizer, 6 g potassium chloride and 2 or 4 g urea according to the treatment shown in Table 1. The nitrogen fertilizer was applied three times during the growing season, at pre-planting, 6th leaf emergence stage (May 31) and heading stage (July 7) at the rate of 2-2-2 g respectively in control. In the treatment, 4 g urea was applied at some stage in the three times respectively, so these rates of nitrogen application, i.e., 2-4-2 g, 2-4-4 g and 2-2-4 g were combined with frequent irrigation (first group), 10 days drought at 6th leaf emergence stage (second group) and first wilting conditions at 12th leaf emergence stage (third group). And then in other treatment, each 4 g urea was applied at three times.

All treatments were irrigated frequently during the growth season in the same manner as the control and the soil moisture was maintained near field capacity, but irrigation was suspended from May 31 to June 10 in order to impose 10 days drought at 6th leaf emergence stage and also irrigation was suspended from June 16 to June 30 to reach first wilting conditions at 12th leaf emergence stage.

Heading occurred at the same time on July 7 for all treatments and the plants were harvested on August 25. The plant height, length of panicle, dry weight of aerial parts of plant and weight of 1,000 grains were measured. The number of leaves per plant and number of grains per panicle were counted. The chemical components of the plants were determined by the following methods: total nitrogen by the sum of kjeldahl nitrogen and nitrate nitrogen[2,17], protein content of grain by total N×6.25 and crude starch by SOMOGY-NELSON's method[9,23].

The data used in Figs. 1, 2 and 3 were calculated from the data given in Tables 3, 5 and 7 of the previous paper respectively. The investigation was composed of following

Table 1. Experimental treatments.

| Treatments | | Nitrogen fertilization (urea (g)/pot) | | | Drought |
|---|---|---|---|---|---|
| | | preplanting | 6th leaf emergence stage | Heading stage | |
| Control | | 2 | 2 | 2 | * |
| | A | 2 | 4 | 2 | |
| First group | B | 2 | 4 | 4 | * |
| | C | 2 | 2 | 4 | |
| | D | 2 | 4 | 2 | 10 days drought |
| Second group | E | 2 | 4 | 4 | at 6 th leaf |
| | F | 2 | 2 | 4 | emergence stage |
| | G | 2 | 4 | 2 | First wilting |
| Third group | H | 2 | 4 | 4 | at 12 th leaf |
| | I | 2 | 2 | 4 | emergence stage |
| | J | 4 | 4 | 4 | * |

*; continuous irrigation.

three experiments. First experiment: four different irrigation treatments, pF 0 to 1.5, 0 to 2.0, 0 to 2.5 and 0 to 2.8 were started when the 4th leaf was fully expanded. When the soil moisture decreased, and when the pF reached 1.5, 2.0, 2.5 and 2.8 in each treatment, the soil was well remoistened until the mercury in tensiometers fell to zero. These irrigation cycles were continued throughout the growing season. Second experiment: in the control, the soil moisture was maintained at all times by daily watering. Nine drought treatments 4, 8, 12, 16, 20, 24, 28, 32 and 36 days were started at the 6th leaf emergence stage when watering ceased, and then the plants were irrigated again at the end of each drought period and irrigated daily in the same manner as the control until harvest time. Third experiment: at each of 9th and 12th leaf emergence stages, heading stage and ten days after heading stage, the soil was left without irrigation for various wilting treatment. At the end of each wilting treatment the soil was well remoistened and then irrigated daily in the same manner as the control until harvest time.

## Results

The growth and grain yield of grain sorghum in relation to the nitrogen fertilization and drought treatments are shown in Table 2. Plant height increased in all treatments than that in control, while there was no significant differences between treatments for plant height. Also no significant differences existed between treatments and control for number of leaves per plant. The length of panicle in control and treated plants followed the same trend as plant height. Although the length of panicle increased with 8 and 10 g nitrogen application compared with control, there was no change in length of panicle with increasing nitrogen fertilizer to 12 g.

The dry weight of vegetative parts (leaf+stem) was greatest in control and decreased gradually with increasing nitrogen application (12 g). The dry weight of panicle and dry weight of vegetative parts were lower in 2–4–4 treatment than that in 2–4–2 and 2–2–4 treatments in all the three groups. Therefore, it seems that the dry weight of vegetative parts decreases with increasing nitrogen application. The dry weight of vegetative parts was higher in the first group than in the other two groups. With slight increase of nitrogen fertilizer, the dry weight of panicle and dry weight of grains per panicle increased in 2–4–2 and 2–2–4 treatments than in control, but decreased in 2–4–4 and 4–4–4 treatments with higher application of nitrogen. Heavier dry weight of panicle and dry weight of grains per panicle were obtained in plants which were treated with a short period of drought

Table 2. Growth and grain yield of grain sorghum under different levels of nitrogen application and drought treatments.

| Treatments | | Plant height (cm) | No. of leaves | Length of panicle (cm) | Dry weight (g) | | No. of grains/ panicle | Grain dry Wt./ panicle (g) | 1,000 grains weight (g) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Leaf+ Stem | Panicle | | | |
| Control | | 126.6 | 16.8 | 24.3 | 30.5 | 20.9 | 621.1 | 16.1 | 25.9 |
| First group | A | 136.9 | 16.7 | 26.0 | 28.3 | 22.9 | 661.9 | 17.8 | 26.9 |
| | B | 136.9 | 16.0 | 26.6 | 26.5 | 18.8 | 574.9 | 13.9 | 24.2 |
| | C | 138.5 | 16.2 | 25.9 | 29.9 | 25.1 | 678.0 | 19.0 | 28.0 |
| Second group | D | 135.3 | 16.7 | 25.9 | 27.0 | 24.5 | 734.5 | 20.0 | 27.2 |
| | E | 134.0 | 16.3 | 25.6 | 25.8 | 20.6 | 660.0 | 17.5 | 26.5 |
| | F | 133.6 | 16.3 | 25.8 | 26.7 | 26.8 | 789.1 | 21.8 | 27.6 |
| Third group | G | 134.6 | 16.4 | 24.7 | 25.3 | 21.4 | 587.2 | 17.0 | 29.0 |
| | H | 138.6 | 16.2 | 25.7 | 25.0 | 18.3 | 518.2 | 14.1 | 27.2 |
| | I | 134.3 | 16.3 | 26.1 | 25.3 | 20.3 | 559.7 | 16.5 | 29.5 |
| | J | 136.1 | 16.4 | 26.0 | 24.6 | 18.4 | 554.9 | 14.4 | 26.0 |

at 6th leaf emergence stage (second group treaments) compared with control and other treatments.

The number of grains per panicle, dry weight of panicle and dry weight of grains per panicle followed the same trend toward drought and nitrogen fertilization. Also the number of grains per panicle remarkably increased in the second group treatments than that in control and other treatments. Weight of 1,000 grains increased in third group treatments compared with control and other treatments. It also increased in 2–4–2 and 2–2–4 treatments compared with control by slight increase of nitrogen fertilizer, but there was no change with increasing nitrogen fertilizer to 12 g compared with control. An increase was obtained in weight of 1,000 grains when nitrogen fertilizer was combined with drought and wilting conditions compared with control and first group treatments.

The grain and forage yields and some chemical compositions of grain sorghum are shown in Table 3. The percent crude protein in grains had a tendency to increased with increasing nitrogen application. Nitrogen content in grains increased in all the 2–4–2 and 2–2–4 treatments than in control, but decreased in all the 2–4–4 and 4–4–4 treatments with increasing nitrogen application. Slight increse of nitrogen and especially when combined with a short period of drought was more effective for increase in grain nitrogen content compared with control. In all treatments, the nitrogen content in the vegetative parts was higher than in control and between treatments the increase was greater with higher application of nitrogen (10 and 12 g), but with the application of 12 g nitrogen (2 times control), the rate of increase of nitrogen in the vegetative parts was not twice that of control. The dry weight of vegetative parts decreased in treatments than in control, but the increase of nitrogen content in the vegetative parts was due to increase of nitrogen concentration. In all treatments, the grain yield and nitrogen content in the grains followed the same trend. But there was an opposite trend between the dry weight and the nitrogen content of vegetative parts. Although a slight increase in percent crude starch in grain was observed with increasing nitrogen application compared with control, there was no significant differences among treatments.

Table 3. Yield and chemical compositions of grain sorghum under different levels of nitrogen application and drought treatments.

| Treatments | | Nitrogen content (mg)/plant* | | Grain crude protein (%) | Grain crude starch (%) |
|---|---|---|---|---|---|
| | | Grain | Other parts | | |
| Control | | 269.7 | 405.7 | 10.5 | 62.8 |
| First group | A | 324.7 | 426.0 | 11.4 | 66.7 |
| | B | 267.9 | 617.3 | 12.0 | 65.8 |
| | C | 319.2 | 480.1 | 10.5 | 62.8 |
| Second group | D | 335.0 | 484.6 | 10.5 | 67.3 |
| | E | 310.6 | 521.4 | 11.1 | 61.5 |
| | F | 350.8 | 450.4 | 10.1 | 63.3 |
| Third group | G | 301.4 | 423.5 | 11.1 | 68.2 |
| | H | 260.5 | 547.4 | 11.3 | 63.8 |
| | I | 298.5 | 516.3 | 11.3 | 66.7 |
| | J | 262.7 | 519.2 | 11.4 | 64.8 |

* Root and head chaff excluded.

## Discussion

*Effect of nitrogen fertilization*

The effect of nitrogen fertilization on the growth and grain yield of grain sorghum have been investigated by Ochi *et al.*[21]. They applied 150 kg farmyard manure per are and 2.5 kg nitrogen as control and 1.0 kg and 4.0 kg nitrogen per are as low and high application respectively. Up to now these workers applied 4.0 kg nitrogen per are in many other experiments. Therefore, it seems that the above experiment was done under low nitrogen level conditions. However, plant height and length of panicle increased with increasing nitrogen application as we observed in our experiment. They obtained higher grain yield in control and at higher nitrogen level than at low level nitrogen application. With increasing nitrogen application, poor ripening was observed, therefore there was a decrease in weight of 1,000 grains and volume weight of grain, and an increase in percentage of smaller grains. There was no difference between control and high nitrogen application under drained paddy field conditions. Therefore, it seems that, the nitrogen level above the control conditions is ineffective.

In this experiment, the length of panicle and plant height increased with 8 g nitrogen application compared with control, but with higher nitrogen application (10 and 12 g) there was no change in these parameters. Although the dry weight of vegetative parts with 8 g nitrogen application slightly decreased compared with control, it substantialy decreased with heavy nitrogen application. It was observed that dry weight of panicle, number of grains per panicle, grain yield and its nitrogen content increased markedly with 8 g nitrogen application compared with control, but these parameters decreased with increasing nitrcgen application. Nitorogen content in vegetative parts and percent crude protein in grains had a tendency to increase in treatments than in control with application of nitrogen. The weight of 1,000 grains increased with the application of 8 g nitrogen compared with control, however, with increasing nitrogen up to 12 g, no significant differences were observed between the treatments and control. From the above observations, it is clear that 10 and 12 g urea per 1/2,000 are WAGNER's pot are heavy application levels and 8 g urea is the optimum level in this experiment. In this experiment optimum nitrogen application level for the growth of grain sorghum was heigher than the report of OCHI *et al.*[21].

It was observed that, with increasing nitrogen application, nitrogen concentration in grains increased and the grain yield decreased, but there was no significant differences for percent crude starch in grain between treatments. These results confirmed the results of our previous water culture experiments[13]. Concentration of nitrogen in grains increased with increasing nitrogen application and therefore the decrease of nitrogen content in grains was due to lower grain yield. The dry weight of vegetative parts decreased with increasing nitrogen application, therefore the increase of nitrogen content in vegetative parts was due to higher concentration of nitrogen. From the data of the percent nitrogen content in grain to nitrogen content in whole plant, it can be said that, with higher application of nitrogen, the absorbed nitrogen accumulated more in the vegetative parts and less translocated into the grains. This observation was similar to that reported in our previous paper[13]. Grain yield and its nitrogen content followed the same trend with increasing nitrogen application, but the forage yield and its nitrogen content followed an opposite trend with increasing nitrogen application.

*Effect of drought and its combination with nitrogen*

As the results of our previous experiments[14,16] the effect of drought was not substantial on the plant height and the number of leaves per plant. For instance, the dry weight of panicle increased in treatments of 10 days drought (second group treatments) compared with treatments irrigated frequently (first group treatments). No effect of drought on the length of panicle have been observed, but in this experiment the length of panicle increased slightly compared with control. It seems to indicate that the increase was caused by nitrogen application.

In our previouse experiment[14] it was observed that dry weight of panicle, grain yield and nitrogen content in grain increased in first wilting treatments compared with these in control. Therefore, those of slight decrease in the third group compared with the first group were unexpected. In this experiment, the number of grains per panicle decreased in plants treated with first wilting at 12th leaf emergence stage as was observed in our previous experiments[14]. This decrease seems to be caused by the drying of soil to impose first wilting at the 12th leaf emergence stage which was almost coincided with young panicle formation stage (11th leaf emergence stage)[15]. The decrease in grain yield and dry weight of panicle in this third group experiment seems to be caused by longer drought period to reach first wilting conditions due to more cloudy and rainy days. We observed some precipitation on every day except only 4 days (June 18, 27, 29 and 30) in the period of this experiment. In our previous experiments[14,16], the time required to reach first wilting conditions was 4 to 6 days and the longest period was 9 days, while in this experiment it took 15 days, therefore, unexpected results were obtained. This result seems to be similar to that of severe drought treatments in the previous experiment[14]. From the results described above, it can be concluded that, if the time required to reach the same degree of wilting (first wilting conditions) is different, the plant responses are also different. So it can be said that, although the growth and grain yield increase when the plant reach first wilting conditions for short period, the growth is damaged in case of long period.

The number of grain per panicle increased than in control with increasing nitrogen application (8 g) and the increase was more remarkable when drought condition was combined with nitrogen fertilizer (second group treatments). This result was the same as that reported previously[14]. Although the percent crude protein in grains increased in all treatments compared with that in control, and was almost the same in all the three groups, the increase in grain nitrogen content in the second group and the decrease in the third group as compared with the first group were due to increase and decrease in grain yield, respectively. The dry weight of grains per panicle and dry weight of panicle followed the same trend with nitrogen fertilization and drought treatments. The weight of 1,000 grains increased with slight increase of nitrogen fertilizer (8 g) than in control and greater weight was obtained when nitrogen fertilizer was combined with drought and wilting conditions.

It is clear from the above observations that the imposition of a short period of drought to plant causes the increase in grain yield, dry weight of panicle, number of grains per panicle, weight of 1,000 grains and nitrogen content in grains compared with control as we observed in our previous experiments[14]. Also enhancement of growth following a short period of drought has been reported in several crop species. Horst *et al.*[10] and Nelson *et al.*[20] showed that irrigation significantly increased summer yield of tall fescue (*Festuca arundinacea* Schreb.). However, in the following fall and spring, there was an unexplained yield compensation by those plants that were water-stressed as compared to those that had been irrigated. Horst and Nelson[11] reported that concentration of water-soluble carbohydrate (WSC) in stem during summer was higher in the water-stressed plants. In the fall, the growth of plants that were water-stressed during summer was greater than those that had been irrigated. The enhancement of growth or compensatory effect was associated with higher concentration of WSC in stem during late summer and faster leaf elongation and greater weight per tiller in fall of the previously water-stressed plants as compared with the summer-irrigated plants. Water stress caused greater protein level in the water-stressed herbage. This agrees with the result of Bennet *et al.*[3] who reported an increase in total nitrogen content for three annual forage species under dryland conditions as opposed to that under irrigation.

Orchard[22] indicated that net assimilation rate of sugar beet (*Beta vulgaris* L.) following drought was significantly greater in plants that were water-stressed than in those previously irrigated. Relative leaf growth rates of drought-stressed plants that had been rewatered were also significantly higher than the concomitant rates for plants irrigated continuously. Corleto and Laude[4] reported a larger number of shoots and increased root growth of annual ryegrass (*Lolium multiflorum* Lam.) that were rewatered after being held for 4 days at the "permanent wilting percentage" as compared to those rewatered when the "permanent wilting percentage" was approached. Stocker[24] reported increased growth rates of warm-season grasses following a drought period. The growth response of young tomato plants (*Lycopersicon esculentum* L.) subjected to wilting treatments of short duration was determined by Gates[5].

The experiments were conducted in pots in the glasshouse, and the wilting treatments were at "moderate" and "severe" levels. Even with the severe treatments, soil water did not fall below the permanent wilting percentage. Both wilting treatments reduced growth during the period of wilting, but the relative growth rates, lamina weight ratios and net assimilation rates were greater upon rewatering than that for the control plants.

From the above observations, it seems that, a brief period of water shortage in the growing term has a positive effect on the plant characters actually, but the reason is not elucidated necessarily and this is problem in future.

On the other hand, in our water cultural experiments[13] with slight increase of nitrogen concentration in the cultural solution, it was observed that grain yield was the highest level at 44 ppm solution throughout whole growing term, but under high concentration of nitrogen grain yield decreased slightly and protein yield increased conversely at 88 ppm solution and so forth. Therefore, it seems that with drying of the soil, the increase of nitrogen concentration in the soil caused the increase of grain and protein yields.

In this experiment, 8 g nitrogen fertilizer was the optimum level and the plant characters definitely decreased with increasing nitrogen fertilizer, i.e., 10 and 12 g. Because 8 g nitrogen fertilizer when combined with a short period of drought remarkably increased the grain and protein yields, it can be assumed that, although concentration of nitrogen in the soil increased during short period of drought due to suspension of irrigation, there was no relationship between increasing concentration of nitrogen in the soil and increasing grain and protein yields. In other words, it was observed that the grain sorghum grew up excellently when it was experienced in short period of drought in vegetative growing stage, even nitrogen application was optimum level.

*Effect of water stress*

As shown in Fig. 1, when the soil moisture content was maintained near field capacity by frequent irrigation on the average 1.3 day intervals (pF 0–1.5), the nitrogen uptake by plant, nitrogen translocation from the vegetative parts into the grains and grain yield increased, but these decreased as soil moisture content decreased (pF 0–2.8). With decrease in soil moisture content, the nitrogen uptake slightly decreased, but the translocation of nitrogen into the grains decreased remarkably. In other words, while the difference between the nitrogen uptake of high (pF 0–1.5) and low (pF 0–2.8) soil moisture conditions was 15%, this difference was 34% for nitrogen translocation into the grains, i.e., at longer interval of irrigation, the moisture was sufficient for the plants to absorb nitrogen from the soil, but was insufficient for translocation of nitrogen into the grains.

It is of interest to note that nitrogen uptake by matured plants and grain yield remarkably increased than in control plant (pF 0–1.5) when a short period of drought (approximately 10 days) was imposed to plant at 6th leaf emergence stage and the plants were rewatered before wilting symptoms were observed. Afterwards, the nitrogen uptake and grain yield in wilted plant

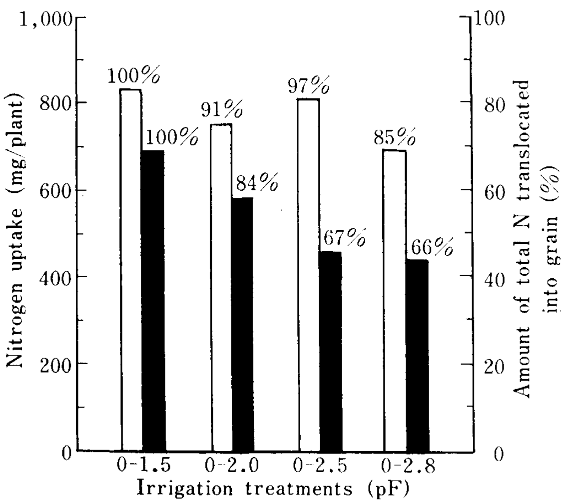


Fig. 1. Nitrogen uptake by matured plant and amount of total nitrogen translocated into grains under different irrigation treatments.

□ : Nitrogen uptake

■ : Amount of total nitrogen translocated into grain $(\%)=\frac{\text{Total N in grain}}{\text{Total N in plant}}\times 100$

gradually decreased as drought period become longer and plant water stress become severe. However, there was no decrease in nitrogen uptake in matured plants and grain yield up to 28 days drought period at 6th leaf emergence stage compared with control plants which were irrigated frequently, after that, nitrogen uptake by plants and grain yield remarkably decreased. But the other hand, no changes were observed in translocation of nitrogen into grains up to 36 days drought period (Fig. 2).

Moderate (A), severe (B) and very severe (C, D) wilting periods were imposed to the plant at 9th and 12th leaf emergence stages, heading stage and early grain filling stage (10 days after heading stage), and nitrogen uptake and translocation of nitrogen into the grains in matured plants were compared under these conditions with control which was irrigated frequently (Fig. 3). It was observed that nitrogen uptake by plant was almost the same as in control when moderate wilting conditions were imposed at 9th and 12th leaf emergence stages, but it increased remarkably than in control (pF 0–1.5) when imposed at later growth stages, i.e., heading stage and early grain filling stage. The nitrogen uptake by plants substantially decreased than in control when the plants wilted severely at 9th and 12th leaf emergence stages, but it was almost the same as in control when severe wilting was imposed at heading stage and early grain filling stage. The nitrogen uptake by plants markedly decreased than in control when plants passed through a very severe wilting conditions at 9th and 12th leaf emergence stages and early grain filling stage, but it was almost the same as in control when plants passed through a very severe wilting conditions at heading stage. Regarding the results of water culture experiment which showed that the daily uptake of nitrogen by plant decreased remarkably at heading stage, it seems that very severe wilting at heading stage had no effect on the uptake of nitrogen by the plant. At any growth stage, the translocation of nitrogen into the grains increased than in control

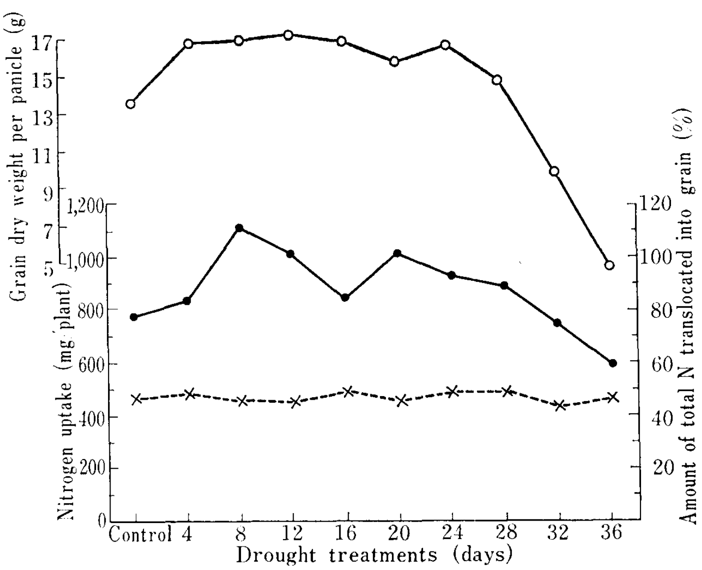


Fig. 2. Nitrogen uptake by matured plant and amount of total nitrogen translocated into grains under different drought treatments imposed at 6th leaf emergence stage.

Control : pF 0—1.5

○——○ : Grain yield

●——● : Nitrogen uptake

×······× : Amount of total nitrogen translocated into grain $(\%)=\frac{\text{Total N in grain}}{\text{Total N in plant}}\times 100$

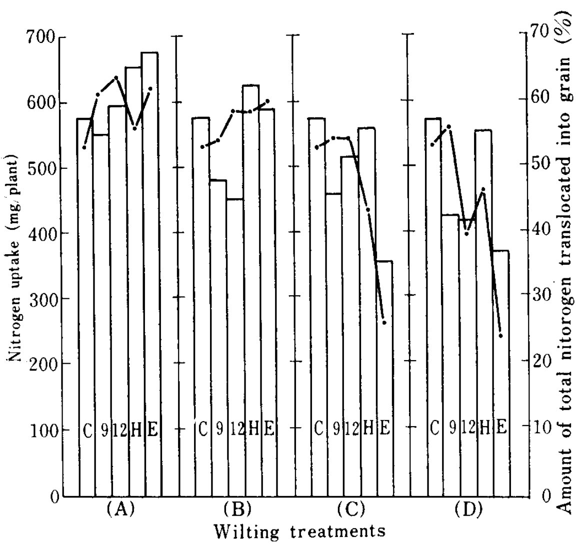


Fig. 3. Nitrogen uptake by matured plant and amount of total nitrogen translocated into grains under different wilting treatments imposed at various stages of growth.

(A) : First wilting.
(B) : Successive wilting.
(C) : Successive wilting+3 days.
(D) : Successive wilting+6 days.
C : Control (pF 0—1.5).
9, 12 : 9th and 12th leaf emergence stage.
H : Heading stage.
E : Early grain filling stage.
●——● : Amount of total nitrogen translocated into grain (%)
$=\frac{\text{Total N in grain}}{\text{Total N in plant}}\times 100$
□ : Nitrogen uptake.

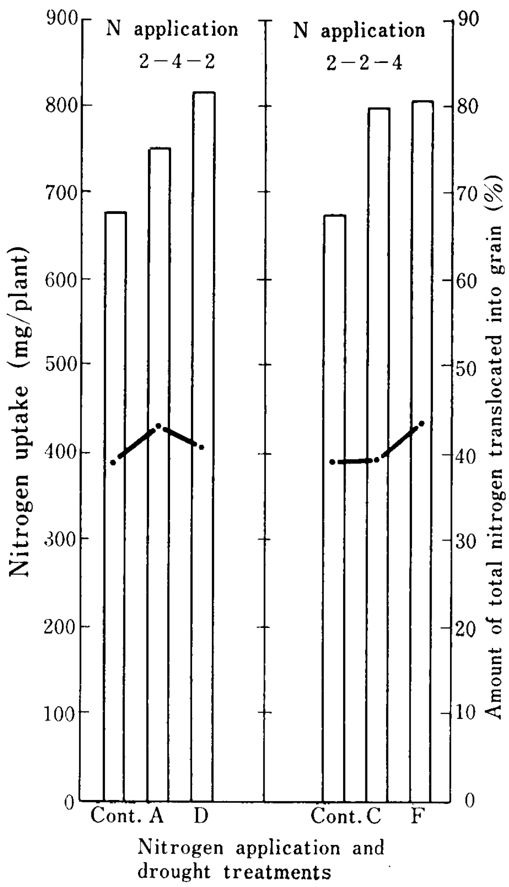


Fig. 4. Nitrogen uptake by matured plant and amount of total nitrogen translocated into grains under nitrogen application and drought treatments.

Control, Treatment A, C, D and F : The same as Table 1.
□ : Nitrogen uptake
●——● : Amount of total nitrogen translocated into grain (%)
$=\frac{\text{Total N in grain}}{\text{Total N in plant}}\times 100$

under moderate and severe wilting conditions, but decreased remarkably under very severe wilting conditions. In the above experiments 6.5 g urea was applied three times during the growing season, at preplanting, 6th leaf emergence stage and flag leaf stage at the rates of 2–3.2–1.3 g in the control and treatments.

In this experiment, it was suggested that 8 g nitrogen per 1/2,000 are WAGNER's pot was the optimum level of nitrogen application. Two methods of application were used for 8 g nitrogen application. 2–4–2 and 2–2–4 (prior to planting, 6th leaf emergence stage and heading stage) and 10 days drought was also imposed at 6th leaf emergence stage. The nitrogen uptake by plant and amount of total nitrogen translocated into the grains under these conditions are shown in Fig. 4.

With the application of 8 g nitrogen fertilizer as 2–4–2 and 10 days drought at 6th leaf emergence stage (Treatment D), nitrogen uptake by plant remarkably increased compared with treatment A, but translocation of nitrogen into the grains slightly decreased. With the application of 8 g nitrogen fertilizer as 2–2–4 and 10 days drought at 6th leaf emergence stage (Treatment F) although nitrogen uptake by plant was almost the same compared with treatment C, a remarkable increase was observed in the amount of total nitrogen translocated into the grains. However, grain yield markedly increased under both conditions, i.e., 2–4–2 g and 2–2–4 g nitrogen fertilizer with 10 days drought at 6th leaf emergence stage compared with non-droughted plants.

In this experiment, it was very difficult that we compared 2–2–4 g with 2–4–2 g nitrogen applicated condition about the effect of nitrogen uptake and nitrogen translocated into grains, because there was only the data of chemical analysis of nitrogen content by matured plant. Therefore, we had to considered in the case of 8 g urea application condition in the lump.

From the above observation, it can be said that drying of the soil for a short period in vegetative growing season resulted in an increase in nitrogen uptake by plant and/or nitrogen translocation into the grains and also increasing grain yield. It was discussed in our previous paper that[16], because the plant response to short period of drought at 6th leaf emergence stage, moderate wilting conditions at 12th leaf emergence stage and hormone spray application of auxin at same both stages was almost the same, and it seems that with a short period of drought auxin content increased in plant and causes plant growth.

It is supposed that increased auxin content in plant is one of the internal factors for acceleration in growth and yield.

## Summary

To determine the optimum level of nitrogen application necessary to obtain higher grain yield and protein content, to investigate whether enhancement of growth, grain yield and protein content in grain sorghum (*Sorghum bicolor* (L.) Moench) hybrid H-726 following a short period of drought is due to increasing nitrogen concentration in the soil during drought period and finally to investigate nitrogen uptake and translocation under the different degrees of water stress and nitrogen application, pot experiment was carried out in the Nagoya University Farm under glasshouse conditions in 1978. The results obtained are summarized as follows:

1. The dry weight of panicle, number of grains per panicle and grain and protein yields increased markedly with 8 g nitrogen application compared with control (6 g), but these parameters decreased with increasing nitrogen application. In this experiment, it was clear that 10 and 12 g urea per 1/2,000 are WAGNER's pot were heavy applications, while 8 g was the optimum level.
2. With increasing nitrogen application, there was an increase in percent crude protein and conversely, grain yield decreased. There was no significant difference for percent crude starch in grain with increasing nitrogen application.
3. From the data of the percent nitrogen content in grain to nitrogen content in whole plant, it can be said that, with higher application of nitrogen, the absorbed nitrogen accumulated more in the vegetative parts and less translocated into the grains.
4. Although the nitrogen concentration in the soil increased during the short period of drought due to suspension of irrigation, no relationship was found between increasing concentration of nitrogen in the soil and increasing grain and protein yields.
5. Imposition of a short period of drought (approximately 10 days) at 6th leaf emergence stage and rewatering before wilting resulted in an increase in grain and protein yields due to enhancement of nitrogen uptake and/or nitrogen translocation even under higher nitrogen application.

## Acknowledgements

The authors express their appreciation to Dr. Shigekata YOSHIDA, Associate Professor, Faculty of Agriculture, Nagoya University, Japan, for his valuable suggestions and Mr. Takeshi NAGATOMO, for his help in this work.

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〔和 文 摘 要〕

## グレインソルガムの生産性に関する研究

### 第5報 窒素の施用量と水分ストレスが穀実収量および窒素の吸収と転流に及ぼす影響

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グレインソルガムの高い穀実収量やたんぱく収量をあげるのに必要な窒素施用の適量を明らかにするため，また短期間の土壌乾燥による土壌中の高窒素濃度が生育，穀実およびたんぱく収量の増加に影響するかどうかを明らかにするため，H-726を用い，ことなる窒素施用量と水分ストレスを組み合わせ，窒素の吸収と転流について調査した．実験は1978年名大農学部附属農場でポットにより行った．得られた結果は次の通りである．

1．穂重．1穂粒数，穀実収量およびたんぱく収量は尿素6g施用に比べ8g施用で明らかに増加したが，さらに施用量を増すと減少した．本実験では，1/2,000a ワグネルポット当たり植物2本立てに対し，尿素10gあるいは12gの施用では多すぎ，8gが適度であることが明らかになった．

2．窒素施用量の増加により穀実収量は減少したが，逆に穀実の粗たんぱく含有率は増大した．穀実の粗でんぷん含有率は窒素施用の増加によって変化がなかった．

3．植物体の窒素含量と穀実の窒素含量の比率から，窒素を多給すると吸収された窒素は茎葉に多く残り，穀実への転流が少なくなるといえる．

4．かん水を中止して短期間乾燥することにより土壌中の窒素含有率が高まるが，この高まりと穀実収量やたんぱく収量との間にはなんの関係も認められなかった．

5．6葉出葉期から10日ほど土壌乾燥を課し，萎凋が現われる前に再びかん水すれば，窒素を多給した場合でも窒素の吸収や転流が高まって，穀実収量やたんぱく収量が増大した．