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The Relationship between the Growth of different Plant Organs of Grain Sorghum Hybrid H-726

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To manage the sorghum crop for maximum production it is necessary to understand how the plant grows and develops. Once the basic growth pattern of grain sorghum plants is understood, it is much easier to judge the merit of changing a management practice. Also, possible effects of entirely new practices can be much better predicted.

The growth of plant organs at different growth stages and under various growing conditions has well been reported, but the growth relations between plant organs during the growth process is unknown. VANDERLIP and REEVES[7] stated that the time required to reach each growth stage depends both on the hybrid and the environment. They identified several growth stages for grain sorghum hybrid RS 610 at Manhattan, Kansas and reported that, while other hybrids growing at other locations would follow the same general growth pattern, the specific timing between growth stages and total number of leaves developed during the growing period may vary among hybrids, seasons, or locations.

On the other hand, external and internal factors affect growth of plant organs and cause retardation and/or acceleration in their growth. To understand the effect of these factors on the growth of plant organs, some standard of measurement is necessary for effective comparison.

The objective of this investigation was to determine the growth process of various plant organs and the relationship between the growth of these organs in grain sorghum hybrid H-726.

Materials and Methods

Pot experiments were conducted in the Nagoya University Experimental Farm under glasshouse conditions. The seeds of grain sorghum (*Sorghum bicolor* (L.) Moench) hybrid H-726 were sown in 1/2000 a WAGNER's pot on April 5, 1977 (first planting) and thinned to 2 plants per pot. The soil was fertilized prior to planting using 2 g urea, 10 g fused phosphatic fertilizer and 6 g potassium chloride. The additional urea application was made at 6th and flag leaf emergence stages at the rates of 3.2 g and 1.3 g per pot, respectively. Ten plants were sampled at the time of each leaf emergence until flag leaf was emerged and after the heading which occurred on June 9 sampling was done 7 times, once a week. After measuring the plant height, the plants were separated into different parts and length and width of leaf blades, length of leaf sheaths, internodes, peduncle and panicle were measured. The roots were referred as P_1, P_2 and E according to the process of root growth, P_1 as initiation of root primordium, E as initiation of root elongation and finally P_2, i.e. the stage between initiation of root primordium and root elongation[6]. Young panicle formation stage was identified by microscopic observations using freezing microtome. The experiment was repeated twice in the same year; the seeds were sown on July 21, and heading occurred on September 7.

Results

The first and second experiments showed almost the same growth patterns. The total number of leaves per plant in the first planting (14 leaves) was less than that obtained in the second planting (16 leaves). Hence, the data of the second planting are discussed in the present paper. Interval of

leaf-emergence was about 3 days and it took about 7 days from flag leaf emergence stage to heading stage.

Table 1 shows the plant height and length of panicle and peduncle at each growth stage. After germination, the plants grew slowly until 5th leaf emergence stage and then grew rapidly. Plants were found to reach about 50% of maximum height at 10th leaf emergence stage. The plants continued to grow and reached maximum height, approximately 140 cm at two weeks after heading stage. Microscopic observations of longitudinal section of the growing point showed vegetative state at 10th leaf emergence stage (Fig. 1) and it became larger, and primordia of primary branches of panicle were visible (Figs. 2 and 3) at 11th leaf emergence stage. Hence, we called 11th leaf emergence stage as young panicle formation stage.

Total lengths of peduncle and panicle were measurable at 13th leaf emergence stage and then began to grow rapidly. Panicle including peduncle was found to reach about 50% of maximum length at heading stage, and maximum length 2 weeks after heading. When the growth of panicle and peduncle was measured separately at heading stage the former reached 86% of its maximum length, however the later was only 36% of the maximum length. Afterwards, peduncle grew rapidly and reached maximum length 2 weeks after heading as well as that of panicle.

Table 2 shows the growth of leaf sheaths with the growth periods. The number of leaf sheaths growing in each of the earlier growth stage were less than that in later growth stage. For instance, at 4th leaf emergence stage, while second leaf sheath had reached its maximum length, only the 3rd and 4th leaf sheaths were elongating, but at 12th leaf emergence stage, while 7th leaf sheath had reached maximum length, the sheaths number 8 to 13 were growing.

Table 1. Development of panicle, peduncle and plant in grain sorghum at various stages of growth.

Growth stages	Plant height		Panicle length		Peduncle length		Panicle+Peduncle length	
	mm	%	mm	%	mm	%	mm	%
2w	1391	100	219	100	558	100	777	100
1w	1263	98	211	96	526	96	737	95
H	1278	92	189	86	202	36	391	50
16	1196	86	59	27	3	1	62	8
15	1127	81	27	12	2		29	4
14	1080	78	11	5	1		12	2
13	1019	73	2	1			2	
12	946	68						
11	835	60	Y					
10	671	48						
9	575	41						
8	427	31						
7	335	24						
6	227	16						
5	145	10						
4	83	6						
3	42	3						
2	23	2						

2-16 : Leaf emergence stages.
16 : Flag leaf emergence stage.
H : Heading stage.
W : Weeks after heading stage.
Y : Young panicle formation stage.

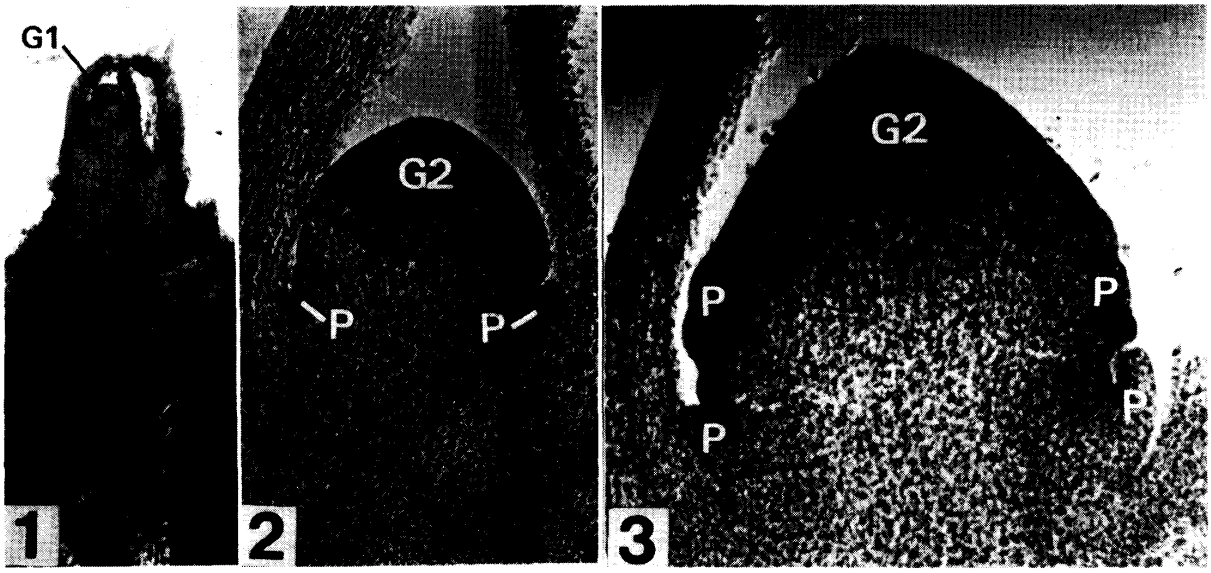

Fig. 1—3. Longitudinal sections of the growing point of grain sorghum at 10 th leaf emergence stage (Fig. 1, × 95 approx.) and 11 th leaf emergence stage (Figs. 2 and 3, × 230 approx.).
G_1 : Growing point (vegetative).
G_2 : Growing point (reproductive).
P : Primordia of primary branches of panicle.

Table 2. Length of leaf sheath expressed as percentage of maximum length in grain sorghum at various stages of growth.

Growth stages	Leaf number														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1w													100	100	100
H										100	100	100	95	92	82
16									100	97	96	86	77	57	30
15								100	98	94	89	60	25	12	7
14							100	99	96	85	72	13	7	2	1
13							98	95	89	67	14	4	1	1	
12						100	93	88	57	10	6	1			
11						97	89	53	6	2	1				
10					100	86	58	6	2	1					
9					93	53	9	1							
8				100	74	6	2								
7			100	75	14	1									
6		100	88	12	2										
5		85	27	1											
4	100	52	5												
3	40	6													
2	27														

Symbols are the same as in Table 1.

On the contrary, the growth of leaf sheaths was faster in lower leaves than in upper leaves. The leaf sheaths grew slowly at the beginning and end of growth, but there was a rapid increase in growth during these two periods.

Table 3 shows the length of leaf blades with the growth stages. The elongation of leaf blade followed almost the same pattern as that of leaf sheath. Comparison of lengths of leaf sheath and leaf blade showed that each leaf blade reached its maximum length one leaf emergence stage earlier than the corresponding leaf sheath in lower leaves, but in the upper leaves, although leaf sheaths began to elongate later than in corresponding blades, the two of them reached maximum length simultaneously, i.e. there was an acceleration in growth of leaf sheaths in upper leaves.

The width of leaf blades were obtained by measuring the widest point of the leaf

Table 3. Length of leaf blade expressed as percentage of maximum length in grain sorghum at various stages of growth.

Growth stages	Leaf number														
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1w													100	100	100
H											100	100	95	91	88
16										100	99	98	88	75	67
15									100	98	96	92	82	56	28
14								100	99	95	94	83	62	31	13
13							100	99	98	93	90	61	27	6	2
12							98	97	94	88	58	28	5	1	
11						100	93	91	79	50	26	9	1		
10						91	86	80	48	20	3	1			
9					100	86	62	40	14	2					
8					94	77	29	12							
7				100	81	36	9								
6			100	86	32	5									
5			83	31	3										
4		100	37	1											
3	100	32	2												
2	34	4													

Symbols are the same as in Table 1.

Table 4. Length of internode expressed as percentage of maximum length in grain sorghum at various stages of growth.

Growth stages	Internode number*											
	5	6	7	8	9	10	11	12	13	14	15	16
2w									100	100	100	100
1w							100	100	98	97	93	91
H					100	100	99	98	89	86	81	67
16				100	95	93	89	81	67	32	10	4
15				96	85	81	54	44	30	17	6	
14			100	75	62	59	27	11	5	4		
13			82	51	37	28	8	5	4	3		
12		100	41	34	22	15	6	4	3			
11		96	22	13	7	4						
10	100	88	13	6	5							

Symbols are the same as in Table 1.

* Internode between node n and node (n+1) is referred to as internode (n+1).

blades. The growth of leaf blade with regard to the length and width followed the same pattern and reached their maximum length simultaneously.

Length of internodes are shown in Table 4. The length of internodes below the 5th internode was not presented in the Table since the measurement was difficult. Comparison of the growth of internode (Table 4) with the growth of leaf sheath, leaf blade (Tables 2 and 3) showed that the time required to reach maximum length was longer for internode than that for sheath and blade. In other words, when the leaf reached maximum length or width, at the same growth stage, the corresponding internode still continued to grow. Also at the same growth stage, the number of growing internodes was more than the number of growing leaves. In upper leaves, the length of leaf sheath and leaf blade and width of leaf blade reached maximum at one week after heading stage, while upper internodes were still growing. These internodes reached the maximum length at 2 weeks after heading stage, i.e. 1 week later than that in leaf.

Table 5. Root development at various stages of growth in grain sorghum.

Growth stages	Node number									
	S	C	1	2	3	4	5	6	7	8
H										P_2
16									E	P_2
15									P_2	P_1
14								E	P_2	P_1
13								P_2	P_1	
12							E	P_2	P_1	
11							P_2	P_1		
10						E	P_2	P_1		
9						P_2	P_1			
8					E	P_2	P_1			
7					P_2	P_1				
6				E	P_2	P_1				
5				P_2	P_1					
4			E	P_2	P_1					
3			P_2	P_1						
2		E	P_2	P_1						
1	E	P_2	P_1							

1-16 : Leaf emergence stage.
16 : Flag leaf emergence stage.
S : Seminal root.
C : Coleoptile root.
P_1 : Initiation of root primordium.
P_2 : Stage between initiation of root primordium and root elongation.
E : Initiation of root elongation.

Table 5 shows the development of roots during the growing process. During the growing season, when 2 leaves appeared on the plant, the roots of a node, referred to as node n in ascending order, began to elongate (E), and the roots of the next node, node (n+1), reached P_2, while the roots of the node (n+2) reached P_1, but there was an exception for seminal root and the roots belonging to node number 8. The growth of roots which belong to node number 8 stopped before elongation under present experimental conditions.

Table 6 is a combination of Table 4, i.e. internode growth and Table 5, i.e. root development. From this Table it was observed that when each lower internode reached maximum length, the roots began to elongate from the base of the internode.

Table 6. Relationship between development of roots and internode at various stages of growth.

Growth	5		6		7		8		9		Internode number*
stages	4		5		6		7		8		Node number
H									P_2	100	
16							E	100	P_2	95	
15							P_2	96	P_1	85	
14					E	100	P_2	75	P_1	62	
13					P_2	82	P_1	51		37	
12			E	100	P_2	41	P_1	34		22	
11			P_2	96	P_1	22		13		7	
10	E	100	P_2	88	P_1	13		6		5	

* See the note for Table 4.
Symbols are the same as in Table 5.

Discussion

The total number of leaves per plant in the first planting (14 leaves) was less than that obtained in the second planting (16 leaves). This might be due to differences in temperature in the two experiments. The average daily temperature from

seeding to heading was 19.1°C for first planting, and 34.3°C for second planting. HESKETH *et al.*[2] reported that in sorghum, leaf numbers increased as temperature rose and as the day became longer. The leaf numbers per plant were greatest at the higher temperature, least at lower temperature, the average difference was almost six leaves per plant in their experiment. ESCALADA and PLUCKNETT[1] also reported that in grain sorghum, low light intensity, short photoperiod and low temperature, resulted in reduced number of leaves. Hence, the data of the second planting are discussed in this experiment.

In this investigation the growth of plant organs was observed throughout the growth cycle. The plants grew slowly at early growth stages and rapidly at the later stages. Eleventh leaf emergence stage was identified as young panicle formation stage. VANDERLIP and REEVES[7] in Manhattan, Kansas for grain sorghum hybrid RS 610 reported that formation of young panicle occurred at approximately 8 leaf stage by their measuring criteria. They counted a leaf when the collar (the point where the leaf blade and leaf sheath are attached) was visible without tearing the plant apart, and the lowest leaf (first leaf) having a rounded tip was not counted. But by our measuring criteria (a leaf was counted when the leaf tip was visible, and the first leaf was also included) it was 11th leaf emergence stage as we found for hybrid H-726. After the 11th leaf emergence stage, panicle grew rapidly until heading stage and the growth was faster than that of peduncle, and at heading stage panicle reached 86% of the maximum length. Peduncle grew slowly until heading stage. At flag leaf emrgence stage peduncle reached only 1% of its maximum length and at heading stage 36% of maximum length. Afterwards, peduncle grew rapidly and reached maximum length simultaneously with panicle. In other words, after heading stage, peduncle began to grow rapidly resulting in exertion of the panicle from flag-leaf sheath. INUYAMA *et al.*[3] reported that drought affected plant height and especially when imposed at booting stage, the peduncle length was shortened. As we observed in this experiment, there was a rapid growth of peduncle at flag leaf emergence stage (approximately booting stage), therefore it seems that drought at the beginning of growth of peduncle retarded growth of peduncle very severely.

Comparison of the data for corn plants[5] with that of present experiment shows that, in general the growth patterns of the leaf blade and sheath are similar for both plants. Detailed comparison of growth shows that there is a linear relationship between emergence of leaves and longitudinal growth of leaves in corn plants, while this relation is sigmoid for grain sorghum.

The leaf blade began to grow earlier than leaf sheath, therefore when leaf blade reached its maximum length, leaf sheath was still growing. Leaf sheath reached its maximum length about one leaf emergence stage later than leaf blade. The relation in the growth between leaf blade and leaf sheath is similar to that of corn plants[5].

There was some relationship between the growth of internodes and rooting behavior in grain sorghum plants, i.e. with emergence of two leaves on the plant, one of the lower internodes reached its maximum length, and at this time the roots primordium began to elongate from the base of the internode. This phenomenon was regular in lower internodes and similar to that of corn plants[4] but there is an exception for upper internode in grain sorghum. KOBAYASHI and Mizutani[6] also reported that in corn plants when the internode begin to elongate, root differentiation soon occurs. This phenomenon is also the same as in grain sorghum.

However, observation of growth patterns in general and the growth of plant organs attached to any node shows that, at first the leaf blade begins to grow in length and width, followed by the leaf sheath, therefore leaf sheath reached its maximum length later than in leaf blade. The internode begins to elongate later than the leaf sheath. The internode began to elongate and root differentiation soon occurred and when the

internode reached maximum length, the roots began to elongate. The above order in growth occurred in each node with the process of growth.

Summary

The basic growth patterns and the relationship between the growth of plant organs was examined in grain sorghum (*Sorghum bicolor* (L.) Moench) hybrid H-726. Leaf-emergence interval was about 3 days and about 7 days were necessary from flag leaf emergence to heading. The results obtained are summarized as follows:

1. Transformation from vegetative to reproductive phase was found to occur at 11th leaf emergence stage. At the heading stage, panicle reached 86% of maximum length although peduncle developed only 36%. Afterwards, those two organs reached maximum length simultaneously. Therefore, peduncle grew rapidly after heading stage resulting in exertion of the head from the flag-leaf sheath. All length of panicle and peduncle as well as plant height reached their maximum at two weeks after heading.

2. Length of leaf sheaths, leaf blades and the width of leaf blades in upper leaves reached maximum one week after heading stage. Length and width of leaf blades reached their maximum simultaneously. The leaf sheaths began to elongate later than the corresponding blades. Although leaf sheaths reached maximum length approximately one leaf emergence stage later than leaf blade in lower leaves, they reached maximum length simultaneously in upper leaves. Therefore, there should have been an acceleration in growth of leaf sheaths in upper leaves.

3. The time required for the upper leaves to reach maximum length was longer than for lower leaves, and the number of leaves growing in each of the later stage of growth were more than that in the earlier growth stage.

4. Length of internodes reached maximum after the corresponding leaf blades and leaf sheaths reached their maximum. Upper internodes reached maximum length two weeks after heading, i.e. one week later than the leaf.

5. Relationship was found to exist between root development and growth of lower internodes, i.e. when an internode began to elongate, root differentiation soon occurred at the base of the internode and when the internode reached maximum length the roots began to elongate. In this case, root elongation took place at the nodes lower than 8th node, at which the roots stopped at the primordium stage.

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〔和 文 摘 要〕

グレインソルガム H-726 の植物体各部発育の相互関係

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本研究はグレインソルガム H-726 について，発育の様相と植物体各部の発育の相互関係を明らかにしようとして行った．ガラス室内のワグネルポットに1977年7月21日に播種して，出穂期は各葉出葉期ごとに，出穂後は1週間ごとに7週間後まで採集した．出葉の間隔は止葉出葉前はおよそ3日，止葉出葉期から出穂期（9月7日）までは7日ほどであった．結果は次のとおりである．

1. 幼穂は11葉出葉期にすでに分化しており，出穂期に全長の86％まで伸長していたが，花柄は36％しか伸長していなかった．しかし花柄は出穂期以後急速に伸長して止葉葉鞘から抽出し，両者は同時に最高値に達した．穂，花柄の長さおよび草丈は出穂後2週間で最高値になった．
2. 上位葉の葉鞘，葉身の長さと葉身幅は出穂後1週間で最高値になった．また葉身の長さと幅は各葉とも同時に最高値になった．同一葉では葉鞘は葉身よりおくれて伸長しはじめ，下位の葉ではおよそ1葉期おくれて最高値になったが，上位の葉では葉鞘の生長速度が早くなり葉身と同時に最高値になった．
3. 最高値に達するのに上位葉は下位葉より長時間を要した．また生育の初期より後期の方が同時に伸長しつづけている葉数が多かった．
4. 節間の伸長は葉身や葉鞘よりおくれて始まり，上位のものは出穂後2週間で最高値に達した．
5. 節間の伸長が始まると間もなく節間部に根が分化し，節間の長さが最高値になると節間の基部から伸長を始めるという相互関係のあることが明らかになった．本実験では伸長した根は第7節部までで，第8節部の根は原基のままでとどまった．