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Effects of Phosphorus and Potassium on Growth, Yield and Fodder Quality of IS 23585 Forage Sorghum Cultivar (*Sorghum bicolor* L. Moench)

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Abstract: This growth analysis experiment was carried out at Khon Kaen University Experimental Farm, Khon Kaen, Northeast Thailand in the 2000, in order to justify the effects of phosphorus (P) and potassium (K) levels added to Yasothon soil series (Oxic Paleustults) on dry matter yield and fodder quality of IS 23585 forage sorghum cultivar. The experiment was laid in a 4×4 factorial arranged in a randomized complete block design (RCBD) with four replications. The P levels used were 0, 37.50, 75.00 and 150.00 kg P_2O_5 ha^{-1} and K levels were 0, 56.25, 112.50 and 225.00 kg K_2O ha^{-1}. The results showed that total dry weight (yield) and other growth parameters in most sampling periods significantly increased with an increase in K levels but the increase was only up to K_1. Higher levels of both P and K had no significant effect on total dry weight (yield) and other growth. There were no consistent trends due to both P and K application rates. However, mean Leaf Area Index (LAI) reached a maximum value of 10.21 (P_3K_3) at 8 weeks after emergence (WAE) and then a decline to 5.37 (P_0K_3) at 10 WAE. K significantly affected LAI only at 2 and 6 WAE. Crop growth rate (CGR) and leaf area duration (D) significantly increased up to K_1, whilst P did not. Both optimum total dry weight of 1,7221 kg ha^{-1} (10 WAE) and seed yields of 5,169 kg ha^{-1} were obtained from P_0K_1. Both P and K had no significant effect on 1000-seed weight. P did not affect brix value, whilst K significantly depressed this parameter. K had no significant effect on crude protein (CP), whilst P did. P had no significant effect on neutral detergent fibre (NDF), whilst K significantly did it. Both P and K had no significant effect on both acid detergent fibre (ADF) and ruminal dry matter degradability (DMD) of the sorghum plants.

Key words: Dry matter yield, fodder quality, forage sorghum, phosphorus, potassium

INTRODUCTION

Forage sorghum (*Sorghum bicolor* L. Moench) has its significant role in livestock production, particularly in the tropical zone where feed stuffs could not meet annual requirements due to many factors such as drought conditions, poor soil fertility and many others. Northeast Thailand, a region of high land located on Korat plateau has been facing with many obstacles in producing high sorghum yield such as erratic rainfall patterns and drought conditions apart from poor soil fertility (Chausavathi and Trelo-ges, 2001). Forage sorghum has been recognised as a fodder crop of high potentiality for livestock production especially in most semi-arid areas of the country (Pholsen *et al*., 1998; Pholsen *et al*., 2001). In Northeast Thailand, drought conditions obviously occur in the cold and hot seasons where it causes many problems in providing feedstuffs for both beef and dairy cattle. In spite of a number of projects being carried out during the past decades such as Khon Kaen Pasture Improvement Project (Anon, 1981-1982), Forage Legume Seed Production Project and also pasture projects of the Department of Livestock Development, Ministry of Agriculture and Cooperatives of Thailand (Manidool and Chantkam, 1986; Pholsen *et al*., 1998; Hare and Phaikaew, 1999; Pholsen *et al*., 2001) but the available data are relatively limited, particularly the data on growth, chemical components and yield of forage sorghum cultivars in relation to phosphorus and potassium chemical fertilizers. Phosphorus (P) has its important role in agriculture although the uptake in the plant tissues could be obviously lesser than 0.5%. P is a constituent source of Adinosine Triphosphate (ATP) compound, an energy being produced in the plant tissues by metabolic processes. It also helps in the establishment of gene blocks and genetic code transfer. It is also an important component of phytin, a chemical compound being used by flower plants for seed formation, longevity and germination. Potassium (K) has its significant role on the translocation of assimilates from source (leaves or green

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parts) to sink (grains or fruits) and the uptake of water. K could activate enzymes greater than sixty different enzymes including sweet taste in different kinds of fruits of the orchard plants (Mangel and Kirkby, 1987; Suksri, 1999). Therefore, it is of a tangible value for research workers in the region to carry out more experiments on forage sorghum cultivars in order to provide adequate data for growers.

MATERIALS AND METHODS

This plant growth analysis experiment was carried out at the Experimental Farm, Faculty of Agriculture, Khon Kaen University during the rainy season (July-November, 2000) to investigate the effects due to P and K chemical fertilizers on growth, dry weight yield, seed yield, brix values, chemical components and ruminal dry matter degradability of the IS 23585 forage sorghum cultivar (*Sorghum bicolor* L. Moench), grown on Yasothon soil series (Oxic Paleustults). The experimental area was initially applied with dolomite at a rate of 3,125 kg ha^{-1} to increase soil pH to a workable level. Three weeks after the application of dolomite the land was ploughed twice followed by harrowing once. The experiment was laid in a 4×4 factorial arranged in a randomized complete block design (RCBD) with four replications. The levels of phosphorus (P) used were 0, 37.50, 75.00 and 150.00 kg P_2O_5 ha^{-1} and potassium (K) levels were 0, 56.25, 112.50 and 225.00 kg K_2O ha^{-1}. Thus the experiment consisted of 16 treatment combinations. They were randomly arranged into plots. Each plot was subdivided into 7 subplots for 7 sampling periods for growth parameter measurements where the works were carried out at two-week intervals. Ten plants were taken from each subplot for dry weight and leaf area $plant^{-1}$ determinations. The plot size used was a 3×4 m with a walking path of 1 and 1.5 m between the plots and the blocks, respectively. Each plot received additional amount of nitrogen (urea) twice at 1 and 6 weeks after emergence (WAE) at a rate of 75 kg N ha^{-1}. One half of both phosphorus and potassium rates were applied by hand to their respective plots as a basal application and the other half was applied at 6 WAE. Seeds of sorghum were sown and drilled into the soil by hand at a distance between by drilling within rows of 50×10 cm, respectively. Carbofuran 3% G insecticide was applied to the soil at a rate of 37 kg ha^{-1} to prevent insect pest damages to seeds at the time of sowing. At 1 WAE, seedlings were thinned out leaving only one seedling $drill^{-1}$.

Weeding was carried out twice by mechanical means at 3 and 6 WAE. At 2 WAE, initial plant samples were taken for the determinations on total dry weight and leaf area $plant^{-1}$. Growth Analysis Technique was used to measure the changes in growth of the aerial plant parts, i.e., total dry weight and leaf area $plant^{-1}$ and other growth parameters where appropriate (Sestak *et al*., 1971; Bullock *et al*., 1993; Suksri, 1999). Leaf areas were measured with the use of leaf area meter (Model No. AAC-440, Hayashi Denko Co., Ltd., Japan). Brix values were determined from juice being squeezed from the middle portion of individual stem at 10 WAE with the use of a Brix Meter (Atago N1, Japan). Crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and ruminal dry matter degradability (DMD) determinations were carried out at 10 WAE (milky stage) with the methods described in Pholsen *et al*. (1998). The results on growth parameters taken at 4, 8 and 12 WAE are not included in this paper since they gave a similar trend in growth parameters as the presented sampling periods, i.e., 2, 4 and 10 WAE. The obtained data were statistically analysed using a SAS Computer Programme (SAS, 1989).

RESULTS

Soil analysis data: The results on initial soil analysis data showed that mean values of soil pH, organic matter, total soil nitrogen, available phosphorus and extractable potassium were 5.85%, 0.67%, 0.036%, 36.75 ppm and 52.75 ppm, respectively. At the final sampling period, mean values of soil pH, organic matter, total nitrogen, available phosphorus and extractable potassium ranged from 6.0-6.30, 0.65-0.7%, 0.0343-0.0406%, 34-85 and 32-84 ppm, respectively.

Growth parameters and brix values: At 2 WAE, total dry weight of the sorghum plants did not increase with an increase in P level. However, an increase in K level significantly increased this parameter but only up to K_2 level. There was no significant difference between K_1 and K_3 (Table 1). Similar results were obtained with stem dry weight, leaf dry weight and leaf area. P levels did not affect all growth parameters except stem dry weight; an increase in P level was similar to the first three levels and later a significant decline for the highest P level. K levels significantly affected leaf area indices (LAI) but there was no consistent trend found. The highest LAI of 0.25 was found with K_2 level. LAI values were relatively small (lesser than 1). This was found in all levels of both P and K. There were no lower dead leaves occurred at this sampling period.

With the sampling period at 6 WAE, an increase in K level significantly increased total dry weight up to K_1, further increases failed to increase this parameter. Total dry weights of the sorghum plants ranged from 6,387 to 6,928 kg ha^{-1} for K_0 and K_3, respectively. A similar trend

Table 1: Total dry weights, stem dry weights, leaf dry weights, leaf areas and leaf area indices (LAI) of the sorghum plants at 2 weeks after emergence (WAE) as influenced by levels of phosphorus (P) and potassium (K) fertilizers, grown on Yasothon soil series (Oxic Paleustults)

	K levels				
P levels	K_0	K_1	K_2	K_3	Average P
Total dry weights (kg ha^{-1})					
P_0	143	143	134	121	135
P_1	127	119	145	139	133
P_2	139	122	187	121	142
P_3	124	103	138	139	126
Average K	133^{b}	122^{b}	151^{a}	130^{b}	
Stem dry weights (g plant^{-1})					
P_0	0.17	0.18	0.15	0.15	0.16^{ab}
P_1	0.15	0.14	0.18	0.16	0.16^{ab}
P_2	0.17	0.15	0.22	0.15	0.17^{a}
P_3	0.15	0.13	0.17	0.16	0.15^{b}
Average K	0.16^{b}	0.15^{b}	0.18^{a}	0.15^{b}	
Leaf dry weights (g plant^{-1})					
P_0	0.55	0.54	0.52	0.46	0.52
P_1	0.48	0.46	0.55	0.54	0.51
P_2	0.53	0.46	0.71	0.46	0.54
P_3	0.48	0.39	0.53	0.53	0.48
Average K	0.51^{b}	0.46^{b}	0.57^{a}	0.50^{b}	
Leaf areas (cm^2 plant^{-1})					
P_0	121	119	114	101	114
P_1	107	99	120	118	111
P_2	116	102	157	101	119
P_3	105	86	116	117	106
Average K	112^{b}	101^{b}	127^{a}	109^{b}	
Leaf area indices (LAI)					
P_0	0.24	0.24	0.23	0.20	0.23
P_1	0.22	0.20	0.24	0.24	0.22
P_2	0.23	0.21	0.31	0.20	0.24
P_3	0.21	0.17	0.23	0.24	0.21
Average K	0.23^{b}	0.20^{c}	0.25^{a}	0.22^{bc}	

Superscript letter(s) within rows and columns indicate significant differences of Duncan's Multiple Range Test (DMRT) at p = 0.05

due to K levels was also found with the results on stem and leaf dry weights, leaf area, LAI and also crop growth rate (Table 2). An increase in P level did not significantly affect all parameters of the sorghum plants. LAI values due to K levels ranged from 7.04 to 7.57 for K_0 and K_2, respectively where LAI values due to P levels ranged from 7.32 to 7.48 for P_0 and P_2, respectively.

At 10 WAE, the results showed that an increase in K level significantly increased total dry weight of the sorghum plants. However, the increase was only up to K_2 level, whilst the highest K_3 level gave a similar total dry weight to K_1. An increase in P level did not affect total dry weight of the sorghum plants (Table 3). Stem dry weight significantly increased with an increase in K level up to K_2 but K_0, K_1 and K_3 levels gave a similar stem dry weight. An increase in P level significantly depressed stem dry weight although P_0, P_1 and P_2 gave a similar stem dry weight plant^{-1}. K levels did not significantly affect leaf dry weight. Leaf dry weights ranged from 12.99 to 13.48 g plant^{-1} for K_0 and K_3, respectively. An increase in P levels did not significantly increase leaf dry weight. Leaf dry weight of P_3 level was similar to P_0. Both P and K

Table 2: Total dry weights, stem dry weights, leaf dry weights, leaf areas, leaf area indices (LAI) and crop growth rates of the sorghum plants at 6 WAE as influenced by levels of P and K fertilizers, grown on Yasothon soil series (Oxic Paleustults)

	K levels				
P levels	K_0	K_1	K_2	K_3	Average P
Total dry weights (kg ha^{-1})					
P_0	6885	7073	6270	7353	6895
P_1	6271	6376	7618	6719	6813
P_2	6126	6884	7364	6880	6754
P_3	6265	7094	6895	6762	6746
Average K	6387^{b}	6856^{a}	7037^{a}	6928^{a}	
Stem dry weights (g plant^{-1})					
P_0	19.25	18.98	17.10	21.42	19.19
P_1	16.73	17.04	21.23	18.30	18.32
P_2	16.00	19.12	20.10	18.73	18.49
P_3	17.08	19.18	19.28	18.56	18.52
Average K	17.26^{b}	18.58^{a}	19.43^{a}	19.25^{a}	
Leaf dry weights (g plant^{-1})					
P_0	15.18	16.39	14.25	15.34	15.29
P_1	14.63	14.85	16.86	15.30	15.41
P_2	14.63	15.30	16.72	15.68	15.58
P_3	14.25	16.29	15.20	15.25	15.25
Average K	14.67^{b}	15.71^{a}	15.76^{a}	15.39^{a}	
Leaf areas (cm^2 plant^{-1})					
P_0	3643	3934	3421	3683	3670
P_1	3512	3563	4048	3672	3699
P_2	3512	3672	4014	3763	3740
P_3	3421	3911	3649	3660	3660
Average K	3522^{b}	3770^{a}	3783^{a}	3694^{a}	
Leaf area indices					
P_0	7.29	7.87	6.84	7.37	7.34
P_1	7.03	7.13	8.10	7.35	7.40
P_2	7.03	7.34	8.03	7.53	7.48
P_3	6.84	7.82	7.30	7.32	7.32
Average K	7.04^{b}	7.54^{b}	7.57^{a}	7.39^{b}	
Crop growth rates (g plant^{-1} week^{-1})					
P_0	278.76	281.53	236.14	288.21	271.16
P_1	245.19	242.81	295.24	266.11	262.34
P_2	226.70	268.18	295.98	268.50	264.84
P_3	240.33	276.38	261.57	253.06	257.83
Average K	247.75^{b}	267.23^{a}	272.23^{a}	268.97^{a}	

Superscript letter(s) within rows indicate significant differences of DMRT at p = 0.05

levels had no significant effects on dead leaf dry weight. Head dry weight significantly increased up to K_1 level and higher K_2 and K_3 levels gave a similar head dry weight to K_1. All of the added P levels gave significant smaller head dry weights than P_0. A similar trend due to P and K application on leaf dry weight was also found with leaf area and LAI (Table 4). Leaf areas ranged from 2,341 to 2,428 cm^2 plant^{-1} for K_0 and K_3 and from 2,262 to 2,507 cm^2 plant^{-1} for P_1 and P_3, respectively. The effect due to P levels was somewhat not clearly found for both leaf area and LAI. LAI values declined more rapidly with time with mean values ranged from 4.53 to 5.01 for P_1 and P_3; and from 4.68 to 4.86 for K_0 and K_3, respectively.

An increase in K level significantly increased CGR of the sorghum plants but only up to K_1, the highest K_3 level failed to increase this parameter. Mean CGR values due to K levels ranged from 21.36 to 27.51 g plant^{-1}week^{-1} for K_3 and K_1, respectively. An increase in P level significantly

Table 3: Total dry weights, stem dry weights, leaf dry weights, dead leaf dry weights and head dry weights of the sorghum plants at 10 WAE as influenced by both P and K fertilizers, grown on Yasothon soil series (Oxic Paleustults)

	K levels				
P levels	K_0	K_1	K_2	K_3	Average P
Total dry weights (kg ha^{-1})					
P_0	14379	17221	17448	16382	16357
P_1	16929	15918	15948	15658	16113
P_2	16394	15127	15770	16073	15841
P_3	14745	16184	16334	15536	15702
Average K	15612^{b}	16113^{ab}	16377^{a}	15912^{ab}	
Stem dry weights (g plant^{-1})					
P_0	48.41	57.75	62.74	54.29	55.79^{a}
P_1	60.38	55.60	54.71	55.02	56.42^{a}
P_2	56.96	50.51	54.97	55.76	54.55^{ab}
P_3	49.98	54.39	55.55	52.24	53.04^{b}
Average K	53.93^{b}	54.56^{b}	56.99^{a}	54.32^{b}	
Leaf dry weights (g plant^{-1})					
P_0	12.14	14.47	13.26	14.90	13.69^{ab}
P_1	13.40	12.32	12.83	11.71	12.56^{c}
P_2	13.24	13.29	12.92	13.14	13.15^{bc}
P_3	13.22	13.64	14.64	14.18	13.92^{a}
Average K	12.99	13.43	13.41	13.48	
Dead leaf dry weights (g plant^{-1})					
P_0	6.05	6.10	5.16	5.60	5.73
P_1	5.82	6.42	6.59	6.12	6.23
P_2	6.62	6.12	4.68	5.30	5.68
P_3	5.33	6.74	5.58	5.46	5.78
Average K	5.95	6.34	5.50	5.62	
Head dry weights (g plant^{-1})					
P_0	5.31	7.79	6.09	7.13	6.58^{a}
P_1	5.06	5.27	5.63	5.45	5.35^{c}
P_2	5.15	5.73	6.30	6.18	5.84^{b}
P_3	5.20	6.16	5.97	5.81	5.78^{b}
Average K	5.18^{b}	6.23^{a}	6.00^{a}	6.14^{a}	

Superscript letter(s) within rows and columns indicate significant differences of DMRT at p = 0.05

Table 4: Leaf areas, leaf area indices, crop growth rates, leaf area duration and brix values, of the sorghum plants at 10 WAE as influenced by P and K fertilizers, grown on Yasothon soil series (Oxic Paleustults)

	K levels				
P levels	K_0	K_1	K_2	K_3	Average P
Leaf areas (cm^2 plant^{-1})					
P_0	2186	2606	2387	2684	2466^{ab}
P_1	2414	2219	2311	2109	2262^{c}
P_2	2384	2394	2326	2366	2368^{bc}
P_3	2382	2457	2636	2553	2507^{a}
Average K	2341	2419	2415	2428	
Leaf area indices					
P_0	4.38	5.21	4.77	5.37	4.93^{ab}
P_1	4.83	4.44	4.62	4.22	4.53^{c}
P_2	4.77	4.79	4.65	4.73	4.74^{bc}
P_3	4.76	4.91	5.27	5.11	5.01^{a}
Average K	4.68	4.84	4.83	4.86	
Crop growth rates (g plant^{-1} week^{-1})					
P_0	25.92	30.54	32.14	26.75	28.85^{a}
P_1	24.41	31.28	26.12	19.51	25.33^{b}
P_2	29.56	26.09	21.13	16.03	23.20^{b}
P_3	18.79	22.13	28.71	23.14	23.19^{b}
Average K	24.67^{b}	27.51^{a}	27.03^{a}	21.36^{c}	
Leaf area duration (m^2 week^{-1})					
P_0	1.92	2.13	2.03	2.16	2.06^{b}
P_1	2.13	2.00	2.20	2.04	2.09^{ab}
P_2	2.03	2.07	2.17	2.26	2.13^{a}
P_3	2.06	2.27	2.13	2.14	2.15^{a}
Average K	2.03^{b}	2.12^{a}	2.13^{a}	2.15^{a}	
Brix (%)					
P_0	11.99	10.77	12.11	11.73	11.65
P_1	11.58	10.61	10.51	10.72	10.85
P_2	12.52	10.65	11.26	11.22	11.41
P_3	11.26	10.46	11.70	10.81	11.06
Average K	11.83^{a}	10.62^{c}	11.39^{ab}	11.12^{ac}	

Superscript letter(s) within rows and columns indicate significant differences of DMRT at p = 0.05

failed to increase CGR of the sorghum plants. Leaf area duration (D) was significantly increased only up to P_1 and K_1 levels. P had no significant effect on brix value, whilst K, in most cases, gave a similar value. Brix values ranged from 10.62 to 11.83% for K_1 and K_0 and from 10.85 to 11.65% for P_1 and P_0, respectively.

Head dry weight, seed yield and 1000-seed weight: An increase in K level significantly increased head dry weight of the sorghum plants only up to K_1. The highest level (K_3) significantly depressed this parameter. Head dry weights were 23.56, 27.59, 28.57 and 25.54 g plant^{-1} for K_0 up to K_3, respectively (Table 5). At P_1 level, head dry weight significantly decreased but further levels gave a similar head dry weight as that of P_0.

The results on seed yields due to treatments were similar to head dry weights. Seed yields ranged from 4,287 to 5,200 kg ha^{-1} for K_0 and K_2; and from 4,615 to 4,879 kg ha^{-1} for P_1 and P_3, respectively. The results on 1000-seed weight showed that both P and K chemical fertilizers had no significant effect on this respect. One thousand seed weight ranged from 29.13 to 30.50 g for K_0 and K_2 and form 29.50 to 29.94 g for P_3 and P_1, respectively.

Table 5: Head dry weights, seed yields and 1000-seed weights of the sorghum plants as influenced by P and K fertilizers, grown on Yasothon soil series (Oxic Paleustults)

	K levels				
P levels	K_0	K_1	K_2	K_3	Average P
Head dry weights (g plant^{-1})					
P_0	22.87	28.40	28.62	26.42	26.57^{a}
P_1	23.96	23.61	30.40	23.48	25.36^{b}
P_2	25.99	29.36	25.99	24.75	26.52^{a}
P_3	21.41	29.01	29.29	27.53	26.81^{a}
Average K	23.56^{c}	27.59^{a}	28.57^{a}	25.54^{b}	
Seed yields (kg ha^{-1})					
P_0	4162	5169	5209	4808	4837^{a}
P_1	4360	4297	5532	4273	4615^{b}
P_2	4731	5344	4731	4505	4827^{a}
P_3	3896	5280	5330	5010	4879^{a}
Average K	4287^{c}	5022^{a}	5200^{a}	4649^{b}	
1000-seed weights (g)					
P_0	28.75	30.75	30.25	29.00	29.69
P_1	30.50	29.25	30.25	29.75	29.94
P_2	29.00	30.00	30.50	29.25	29.69
P_3	28.25	30.25	31.00	28.50	29.50
Average K	29.13	30.06	30.50	29.13	

Superscript letter(s) within rows and columns indicate significant differences of DMRT at p = 0.05

Crude protein (CP), neutral and acid detergent fibres (NDF and ADF) and dry matter degradability (DMD): At 10 WAE (milky stage), the results showed that an increase in K level did not increase CP of the sorghum plants,

Table 6: Crude protein, neutral and acid detergent fibres (NDF and ADF) and ruminal dry matter degradability (at 48 h in beef cattle rumen) of the sorghum plants at 10 WAE as influenced by P and K fertilizers, grown on Yasothon soil series (Oxic Paleustults)

	K levels				
P levels	K_0	K_1	K_2	K_3	Average P
Crude protein (% on dry matter basis)					
P_0	8.15	8.28	7.95	7.76	8.04[b]
P_1	9.97	8.61	9.13	8.47	9.04[a]
P_2	8.43	8.89	8.93	8.72	8.74[ab]
P_3	9.37	9.96	9.10	9.06	9.37[a]
Average K	8.98	8.94	8.78	8.50	
NDF (% on dry matter basis)					
P_0	62.73	61.97	61.65	62.74	62.27
P_1	60.62	62.47	62.67	62.66	62.10
P_2	59.92	61.38	62.02	64.47	61.95
P_3	60.58	61.21	61.40	62.17	61.34
Average K	60.96[b]	61.75[ab]	61.93[ab]	63.01[a]	
ADF (% on dry matter basis)					
P_0	36.49	36.94	36.16	37.25	36.71
P_1	36.09	36.69	36.46	36.01	36.31
P_2	34.85	36.41	35.85	37.70	36.20
P_3	35.33	33.94	36.59	36.31	35.54
Average K	35.69	36.00	36.26	36.82	
Dry matter degradability (%)					
P_0	60.51	62.30	60.39	63.28	61.62
P_1	62.91	62.46	63.32	64.61	63.32
P_2	63.72	63.67	64.01	61.79	63.30
P_3	63.76	62.94	65.03	61.32	63.26
Average K	62.72	62.84	63.19	62.75	

Superscript letter(s) within rows and columns indicate significant differences of DMRT at p = 0.05

whilst an increase in P level significantly increased this parameter over the control treatment (P_0). However, higher P levels gave a similar result as P_1. CP percentages ranged from 8.50 to 8.98 for K_3 and K_0 and from 8.04 to 9.37 for P_0 and P_3, respectively (Table 6). P levels had no significant effect on NDF but an increase in K level significantly increased this parameter but only up to K_1. Further increases in K levels gave a similar NDF value to K_1. NDF ranged from 60.96 to 63.01% for K_0 and K_3 and from 61.34 to 62.27% for P_3 and P_0, respectively. Both P and K had no significant effect on ADF and DMD of the sorghum plants. ADF values ranged from 35.69 to 36.82% for K_0 and K_3 and from 35.54 to 36.71% for P_3 and P_0, respectively. DMD percentages ranged from 62.72 to 63.19 for K_0 and K_2 and from 61.62 to 63.32 for P_0 and P_1, respectively.

DISCUSSION

A series of forage sorghum experiments has been carried out at Khon Kaen University Experimental Farm, Thailand in order to select the best cultivar suited most to environmental conditions and the effects due to soil nutrients on growth and grain yields of the selected forage sorghum cultivar in relation to Yasothon soil series, a soil series under the great soil group of Oxic Paleustults, where it belongs to the order Ultisols (Shelton *et al*., 1979; Pirmpoon, 1984; Soil Survey Staff, 1998). The results derived from selection experiment revealed that IS 23585 forage sorghum cultivar was considered to be one of the best two forage sorghum cultivars adapted well to Northeast Thailand (Pholsen *et al*., 1998; Pholsen *et al*., 2001), thus this cultivar was chosen for this investigation.

The results on the initial soil analysis data of Yasothon soil series revealed that this soil type contained some relatively small amounts of nitrogen (N) and potassium (K), whereas phosphorus (P) contents were relatively high. The high mean values of soil P may be attributable to the previous history of crop cultivation where some large amounts of P must have been added to the soil by more or less with the use of chemical fertilizers. Yasothon soil series (Oxic Paleustults) normally contained P lesser than 17 ppm. This level of P may be considered to be an inadequate amount for growth of most crops since critical level for this soil type commences from 25 ppm (Tippayaruk *et al*., 1976; Shelton *et al*., 1979).

With total dry weights, stem dry weights, leaf dry weights and leaf areas at the initial sampling period (2 WAE), the results showed that an increase in K level significantly increased these growth parameters of the sorghum plants. However, the increases were only up to K_2, whilst K_3 level was similar to that of K_1. The results suggested that these growth parameters could possibly have been affected by an inadequate amount of soil moisture content due to the poor distribution of rainfalls and partly due to the low amount of soil organic matter (0.68%). The sorghum plants being fed by rainwater alone may not be of high advantage due to erratic rainfall patterns resulting in both low amount of growth and the poor soil moisture content. LAI values during the early growth period for all P and K levels were relatively small due to its age of a seedling stage where small values of LAI ensure no shading effect on light interception from the sun among leaf canopies.

At 6 WAE, the results showed that total dry weights and other growth parameters were significantly increased with an increase in K level but only up to K_1 whereas the effects due to P level were not found. This could have been attributed to the inadequate amount of soil moisture contents as previously discussed. Some similar trends on LAI and crop growth rates (CGR) due to K and P levels were found as that of total dry weights. It may be inferred that if adequate amount of soil moisture contents were adequately available throughout the growth period then a greater effect due to K and P levels could possibly be achieved. LAI were relatively high reaching an optimum value of 8.10 for P_1K_2 treatment and the lowest of 6.84 for P_0K_2 treatment. The results indicated that the sorghum plants had reached its optimum LAI indicating that more than 90% light distribution must have been distributed among leaf canopies of the sorghum plants. Thus there were no competitions for radiant energy among the leaf canopies of the sorghum plants. LAI values for this type of vertical leaf structure should be in a range of 8-10 (Suksri, 1999).

At 10 WAE, the results revealed that total dry weights were significantly increased with an increase in K level but only up to K_2. This trend was not found with an increase in P level, i.e., P had no significant effect on total dry weight of the sorghum plants. Stem dry weights were also having a similar trend to that of the total dry weight but the effects due to K level application were not found with leaf dry weights, dead leaf dry weights and leaf areas. This may be attributable to the inadequate amount of soil moisture content as previously discussed. Nevertheless, it could have been possible that higher levels of both P and K affected the uptake of nitrogen, i.e., too much of one element depresses the uptake of the others (Mengel and Kirkby, 1987; Suksri, 1999). At this sampling period, a number of lower leaves died off indicating low amounts of soil moisture content and high environmental temperatures but from the analysis it revealed that both P and K levels had no significant effect on dead leaf dry weight. The rapid died off of the lower leaves must be attributable to the inadequate amount of soil moisture content apart from the senescence of lower leaves together with the high environmental temperatures (with average values of 7.2 mm for rainfall day^{-1} and temperature of 27.3°C in the month of September 2000). In most of the tropical areas, it is obviously found that high environmental temperatures hasten maturity age of leaves of most crop plants. Another reason for this could be due to the re-translocation of some nutrients to the grains or young leaves when soil moisture content was not adequately available, particularly nitrogen, thus lower aging leaves died off slowly (Evans, 1975; Suksri, 1999; Pholsen *et al*., 2001). At this growth stage, the sorghum plants had developed a full head of grains and it had reached a milky stage where head dry weight significantly increased with an increase in K level but only up to K_1. Whilst the added P levels gave a decline in this parameter where head dry weight of the control treatment (P_0) was significantly greater than those of the added P treatments. This may be attributable to the imbalance of macronutrients particularly nitrogen together with the poor level of soil moisture content as previously discussed. Some similar effects due to K were also found with leaf area, i.e. K failed to increase leaf area and LAI of the sorghum plants whereas CGR values and leaf area duration (D) were significantly increased with an increase in K level but only up to K_1. P levels had no significant effect on brix values whereas K_1 significantly depressed this parameter, whilst higher K levels gave a similar brix value as that of K_0. This could have been attributed to the low amount of soil moisture content where the supply of soil K was not adequately available, although the results on extractable K was relatively high reaching a value of 84 ppm. Thus K was not able to promote high percentages of brix values resulting in low amounts of sugar content in the stems of the sorghum plants. It is generally known that K promotes sweetness in orchard fruits and juices of sugarcane plants (Suksri, 1999). The results also indicated that higher levels of both P and K failed to provide a clearer effect on CGR and D. This could have been attributed to the inadequate amount of soil moisture content as previously discussed.

Seed yields were significantly influenced by K level but only up to K_1, whilst P did not. Both P and K had no significant effect on 1000-seed weight. This could possibly have been attributed to the inadequate amount of rainwater of erratic rainfall pattern when drought conditions occurred at the end of the rainy season and perhaps the imbalance of macronutrients had a significant effect on seed yield, thus seed yield was relatively low (Suksri, 1999). Therefore, it could have been better for the growth of the sorghum plants if sprinkler irrigation water had been provided so that adequate amount of soil moisture content could be insured. Seed yields were similar to those reported by Tippayaruk *et al*. (1976) and Jaisil *et al*. (1980).

The results on CP % carried out at a milky stage (10 WAE) revealed that K had no effect on CP, whilst P significantly increased it but only up to P_1. This may be attributable to the significant property of P in encouraging the uptake of nitrogen (N) where P failed to encourage the uptake of nitrogen due to low level of soil moisture content as reported by Jaisil *et al.* (1980) and Hare and Chaisang Phaikaew (1999). P had no significant effect on NDF content but K did, i.e., K encouraged the production of fiber of the plant tissues. Both P and K had no significant effect on ADF and also DMD of the sorghum plants. The CP percentages found with this work were much greater than those reported by Butterworth (1985) and Pholsen *et al.* (1998) but similar to those reported by Khajarern *et al.* (1977).

From the results of this research, it may be inferred that IS 23585 forage sorghum cultivar grown on Yasothon soil series (Oxic Paleustults) requires optimum application rate of K fertiliser at a rate of 56.25 kg K_2O ha^{-1} (K_1) and P fertiliser at P_0 and nitrogen (urea) at a rate of 150 kg N ha^{-1} where it gave an optimum total dry weight of 17,221 kg ha^{-1}, seed yield of 5,169 kg ha^{-1}, brix value of 10.77%, CP of 8.28%, NDF of 61.97%, ADF of 36.94% and DMD of 62.30%. Further experiments may be needed in order to provide information on growth, seed yield and other important measurement parameters for growers of this forage sorghum when adequate amounts of soil moisture content could be kept at a level near field capacity of 13% throughout the experimental period then a clearer effect due to both P and K chemical fertilizers may be achieved.

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