THE OXALATE CONTENT OF SOME QUEENSLAND PASTURE PLANTS.

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SUMMARY.

The water-soluble and total oxalate contents of 80 *species of pasture plants were determined by K. W. Moir's modification (in press) of the method of Myers. The results are expressed as percentage of oxalic acid on a moisture-free basis.*

Thirty-four species contained less than 0·5 *per cent. total oxalate.*

Seventeen species contained high levels of total oxalate (4·0 *per cent. or more). One was a grass (Panicum antidotale); the others, all herbage (or forb) plants, were Abutilon oxycarpum, Amaranthus mitchelli, Atriplex muelleri, Atriplex semibaccata, Bassia echinopsila. Chenopodium auricomum, Chenopodium hubbardii, Chenopodium triangulare, Emex australis, Enchylaena tomentosa, Oxalis corniculata, Portulaca oleracea, Salsola kali, Tetragonia expansa, Threlkeldia proceriflora and Trianthema portulacastrum.*

Seventeen grasses were examined; the only one with a significant oxalate content was Panicum antidotale with 3·5 *per cent. soluble and* 4·9 *per cent. total oxalate.*

Oxalate content is highest in immature plants, and it varies with rainfall and probably also with soil and other environmental factors.

Field and experimental evidence on poisoning of sheep and cattle by Portulaca oleracea, Salsola kali, Trianthema portulacastrum and Threlkeldia proceriflora is described and discussed. Because of their high oxalate content, these plants can cause acute poisoning, particularly in hungry or travelling stock.

INTRODUCTION.

The oxalate content of plants grazed by sheep in Queensland first attracted attention because elsewhere the toxicity of a number of species had been attributed to their high content of oxalate or oxalic acid (Fleming, 1928; Bull, 1929; Steyn, 1934). In 1948, the Department became interested in oxalate intake as one of the factors possibly associated with the occurrence of carbonate calculi in the urinary tract of sheep. The oxalate content of a number of the pasture plants grazed by sheep in Queensland was therefore determined, and the results are presented in this paper.

METHODS.

Samples of about 2 lb. of the whole of the aerial part of each plant were collected by field officers of the Department of Agriculture and Stock. Botanical identifications were made in the Queensland Herbarium. Samples were air-dried and then ground in a Wiley mill.

The method of analysis for oxalate was a modification by Moir (1953, in press) of the method described by Myers (1947).

The results are expressed as oxalic acid on a moisture-free basis. Where the total oxalate content was less than 0·5 per cent., soluble oxalate was not determined and was recorded as negative.

RESULTS.

The soluble and total oxalate contents of the 80 plant species examined, together with the localities from which the samples were obtained, are shown in Table 1.

Thirty-four species contained virtually no oxalate—i.e., less than 0·5 per cent. total oxalate.

Seventeen species contained high levels of oxalate—i.e., 4·0 per cent. or more. One was a grass (*Panicum antidotale*). The others (all herbage plants, or forbs) were:—*Abutilon oxycarpum, Amaranthus mitchellii* (boggabri), *Atriplex muelleri* (annual saltbush), *Atriplex semibaccata* (creeping saltbush), *Bassia echinopsila* (red burr), *Chenopodium auricomum* (blue bush), *Chenopodium hubbardii* (a saltbush), *Chenopodium triangulare* (a fishweed), *Emex australis* (spiny emex), *Enchylaena tomentosa* (berry cotton-bush), *Oxalis corniculata* (wood sorrel), *Portulaca oleracea* (pigweed), *Salsola kali* (soft roly-poly), *Tetragonia expansa* (New Zealand spinach), *Threlkeldia proceriflora* (soda bush), and *Trianthema portulacastrum* (black pigweed).

The marked variation in the oxalate content of samples of the same species collected in different localities and at different times is shown particularly by the results for *Portulaca oleracea* and *Salsola kali.* The figures for *Salsola kali* show also the importance of stage of growth of the plant in relation to oxalate content; in particular, a single sample was divided into two parts (plants under 6 in. and plants 6-18 inches high), which were then analysed separately with the following results:—

	Soluble Oxalate	Total Oxalate.
	%	%
Plants under 6 in.	10·7 ..	15·7
Plants 6-18 in.	9·5 ..	13·8

Variations in the oxalate content of samples of *Atriplex semibaccata* and *Tetragonia expansa* collected at approximately monthly intervals from a pasture at Goondiwindi are shown in Fig. 1, together with the monthly rainfall. In each species the young, succulent plants contained much more oxalate than the mature plants.

Table 1.

SOLUBLE AND TOTAL OXALATE CONTENT OF SAMPLES OF 80 SPECIES OF PASTURE PLANTS.
(Expressed as percentage of oxalic acid on a moisture-free basis.)

Species.	Locality and Remarks.	Oxalate.	
		Soluble.	Total.
Abutilon malvifolium	Barcaldine	*	1·5
Abutilon otocarpum	Goondiwindi	—	—
	Goondiwindi	—	1·7
Abutilon oxycarpum	Goondiwindi	—	5·9
Acacia cambagei	Barcaldine	—	—
Alternanthera nodiflora	Barcaldine	1·3	3·7
	Longreach	0·6	2·5
Amaranthus mitchellii	Barcaldine	4·6	7·2
Aristida latifolia	Barcaldine	—	—
	Winton	—	0·2
Astrebla lappacea	Winton	—	—
Astrebla (mixed species)		—	—
Atriplex muelleri	Barcaldine	4·5	6·2
	Barcaldine	4·0	7·0
Atriplex semibaccata	Goondiwindi—Dec. 1948	3·5	4·9
	Goondiwindi—Mar. 1949	3·3	4·6
	Goondiwindi—May 1949	2·3	3·8
	Goondiwindi—June 1949	2·5	3·7
	Goondiwindi—July 1949	2·5	4·0
	Goondiwindi—Aug. 1949	0·6	1·9
	Goondiwindi—Nov. 1949 (young)	7·4	8·3
	Goondiwindi—Dec. 1949	6·4	10·0
	Goondiwindi—Jan. 1950	2·8	4·1
	Goondiwindi—Sept. 1950 (young)	7·4	10·2
Basilicum polystachyon	Longreach	—	0·8
Bassia anisacanthoides	Barcaldine	0·5	5·7
Bassia echinopsila	Isisford	Trace	7·9
	Blackall	—	3·0
	Winton	0·9	2·4
	Winton	5·1	7·5
Bassia quinquecuspis	Winton	2·2	2·4
Bassia tricuspis	Isisford	—	2·5
Boerhavia diffusa	Goondiwindi	0·5	3·6
Bothriochloa ewartiana	Winton	—	—
Brachiaria purpurascens	Barcaldine	0·5	1·1
Brachycome curvicarpa	Barcaldine	—	0·5
Bulbine bulbosa	Isisford	—	—
Calotis lispidula	Isisford	—	Trace
	Winton	—	—
Cassia occidentalis	Winton	—	—
Cassinia laevis	Barcaldine	—	—
Chenopodium auricomum	Longreach	2·1	4·6
Chenopodium hubbardii	Goondiwindi—June 1949 ..	6·3	6·5
	Goondiwindi—Nov. 1949	4·8	7·2
	Goondiwindi—Aug. 1950	4·9	8·7
	Goondiwindi—Sept. 1950	1·4	7·6
Chenopodium triangulare	Dalby	4·3	5·5
Cucumis myriocarpus (fruit) ..	Longreach	—	—

Table 1—continued.

SOLUBLE AND TOTAL OXALATE CONTENT OF SAMPLES OF 80 SPECIES OF PASTURE PLANTS—*continued.*

(Expressed as percentage of oxalic acid on a moisture-free basis.)

Species.	Locality and Remarks.	Oxalate.	
		Soluble.	Total.
Cucumis trigonus (fruit)	Longreach	—	—
(dry vine) ..	Longreach	—	—
Cyperus dactylotes	Goondiwindi	—	—
Cyperus gilesii	Barcaldine	—	—
Dactyloctenium radulans	Barcaldine	—	0·5
Daucus glochidiatus	Winton	—	0·8
	Barcaldine	—	—
	Isisford	—	2·5
Dichanthium sericeum	Barcaldine	—	—
Emex australis	Toowoomba	2·0	6·0
Enchylaena tomentosa	Dalby	6·5	6·7
	Goondiwindi	6·6	6·9
	Longreach	6·7	7·2
Enneapogon flavescens	Barcaldine	—	—
Eragrostis setifolia	Barcaldine	—	—
Eremophila maculata	Longreach	—	2·1
Eriochloa pseudoacrotricha	Winton	—	—
	Barcaldine	—	—
	Goondiwindi	0·4	0·9
Euphorbia drummondii	Longreach	—	0·5
	Winton	—	—
	Barcaldine	—	—
Gnaphalium japonicum	Barcaldine	—	—
Goodenia strangfordii	Winton	—	—
Iseilema membranaceum	Winton	—	—
Iseilema vaginiflorum	Barcaldine	—	—
Kochia coronata	Barcaldine	—	2·0
Lepidium hyssopifolium	Longreach	—	—
Leptochloa digitata	Goondiwindi	—	—
Malvastrum spicatum	Barcaldine	*	2·5
	Barcaldine	—	0·8
	Winton	—	0·5
	Longreach	—	1·5
Minuria integerrima	Longreach	—	—
Neptunia gracilis	Barcaldine	—	0·9
Nicotiana megalosiphon	Barcaldine	—	—
Oxalis corniculata	Goondiwindi	4·1	7·0
Owenia acidula	Longreach	—	3·4
Panicum antidotale	Goondiwindi	3·5	4·9
Panicum maximum	Brisbane	0·5	1·5
Paspalidium caespitosum	Goondiwindi	0·9	1·2
Phyllanthus maderaspatensis ..	Longreach	—	—
	Longreach	—	—

Table 1—continued.

SOLUBLE AND TOTAL OXALATE CONTENT OF SAMPLES OF 80 SPECIES OF PASTURE PLANTS—*continued.*

(Expressed as percentage of oxalic acid on a moisture-free basis.)

Species.	Locality and Remarks.	Oxalate.	
		Soluble.	Total.
Plantago varia	Winton	—	—
	Barcaldine	—	—
	Isisford	—	—
	Goondiwindi—4 samples	—	—
Portulaca oleracea	Brisbane	*	3·5
	Dalby	4·3	5·5
	Dalby	6·8	9·0
	Millmerran	*	6·1
	Blackall	*	9·0
	Barcaldine	*	10·6
	Longreach	7·4	9·3
	Longreach	8·5	11·1
	Longreach	9·4	13·3
	Cunnamulla‡	5·1	7·9
	Cunnamulla‡	4·6	7·7
	Emerald	5·0	8·3
	Longreach	*	10·7
Psoralea cinerea	Winton	—	0·8
Pterigeron odorus	Longreach	—	0·5
Pterocaulon sphacelatum	Longreach	—	0·4
Salsola kali	Barcaldine	2·0	5·0
	Winton—Mature	4·0	10·3
	Winton—Green, 18″	4·8	6·2
	Winton—Green, 6–18″	6·4	6·6
	Longreach—Green, 12″	4·5	7·8
	Winton†—Green, less than 6″	10·7	15·7
	Winton†—Green, 6–18″	9·5	13·8
Senecio lautus	Barcaldine	—	—
Sida fibulifera	Longreach	—	2·0
	Longreach	—	1·3
	Longreach	—	—
Sida trichopoda	Barcaldine	—	1·1
	Longreach	—	—
Solanum esuriale	Barcaldine	*	2·4
	Barcaldine	—	2·8
Solanum nigrum	Winton	—	—
Sphaeranthus hirtus	Longreach	—	1·2
Tetragonia expansa	Dalby	6·6	7·1
	Goondiwindi—Dec. 1948	6·0	7·7
	Goondiwindi—May 1949	6·1	7·8
	Goondiwindi—June 1949	2·3	4·3
	Goondiwindi—July 1949	4·9	6·6
	Goondiwindi—Aug. 1949 (old)	1·5	2·9
	Goondiwindi—Aug. 1949 (young)	11·1	12·1
	Goondiwindi—Oct. 1949 (young)	11·7	13·4
	Goondiwindi—Nov. 1949	12·0	13·1
	Goondiwindi—Dec. 1949	11·2	12·1

Table 1—continued.

SOLUBLE AND TOTAL OXALATE CONTENT OF SAMPLES OF 80 SPECIES OF PASTURE PLANTS—*continued.*

(Expressed as percentage of oxalic acid on a moisture-free basis.)

Species.	Locality and Remarks.	Oxalate.	
		Soluble.	Total.
	Goondiwindi—Jan. 1950	7·7	8·9
	Goondiwindi—Aug. 1950	6·2	8·8
	Goondiwindi—Sept. 1950	6·0	11·0
Teucrium integrifolium	Longreach	..	2·0
Threlkeldia proceriflora	Barcaldine	2·0	3·6
	Barcaldine	6·2	8·6
Trianthema portulacastrum ..	Emerald	7·7	9·6
Tribulus terrestris	Barcaldine	*	0·4
Triraphis mollis	Winton	—	0·1
Verbena officinalis	Barcaldine	—	2·6
	Goondiwindi	—	—
	Longreach	—	—
Verbesina encelioides	Goondiwindi	—	0·4
Vittadenia pterochaeta	Barcaldine	—	—
Vittadenia triloba	Goondiwindi	—	0·5

* Not analysed for soluble oxalate.

† One sample from a single stand of this species was separated into two parts (plants less than 6 in. high and plants 6-18 in. high) and each part analysed separately.

‡ The Queensland Herbarium advised that these two samples from the same area in May, 1952, could be *Portulaca intraterranea* or *Portulaca oleracea* as it is not possible to distinguish these species without good flowering specimens.

Of the 17 grasses examined, only one contained a significant amount of oxalate—viz., *Panicum antidotale,* with 3·5 per cent. soluble and 4·9 per cent. total oxalate. Three species—*Brachiaria purpurascens, Panicum maximum* and *Paspalidium caespitosum*—contained from 1.0 per cent. to 1.5 per cent. total oxalate, while the following grasses contained less than 0.5 per cent. total oxalate:—*Aristida latifolia, Astrebla lappacea, Astrebla* (mixed species), *Bothriochloa ewartiana, Dactyloctenium radulans, Dichanthium sericeum, Enneapogon flavescens, Eragrostis setifolia, Eriochloa pseudoacrotricha, Iseilema membranaceum, Iseilema vaginiflorum, Leptochloa digitata,* and *Triraphis mollis.*

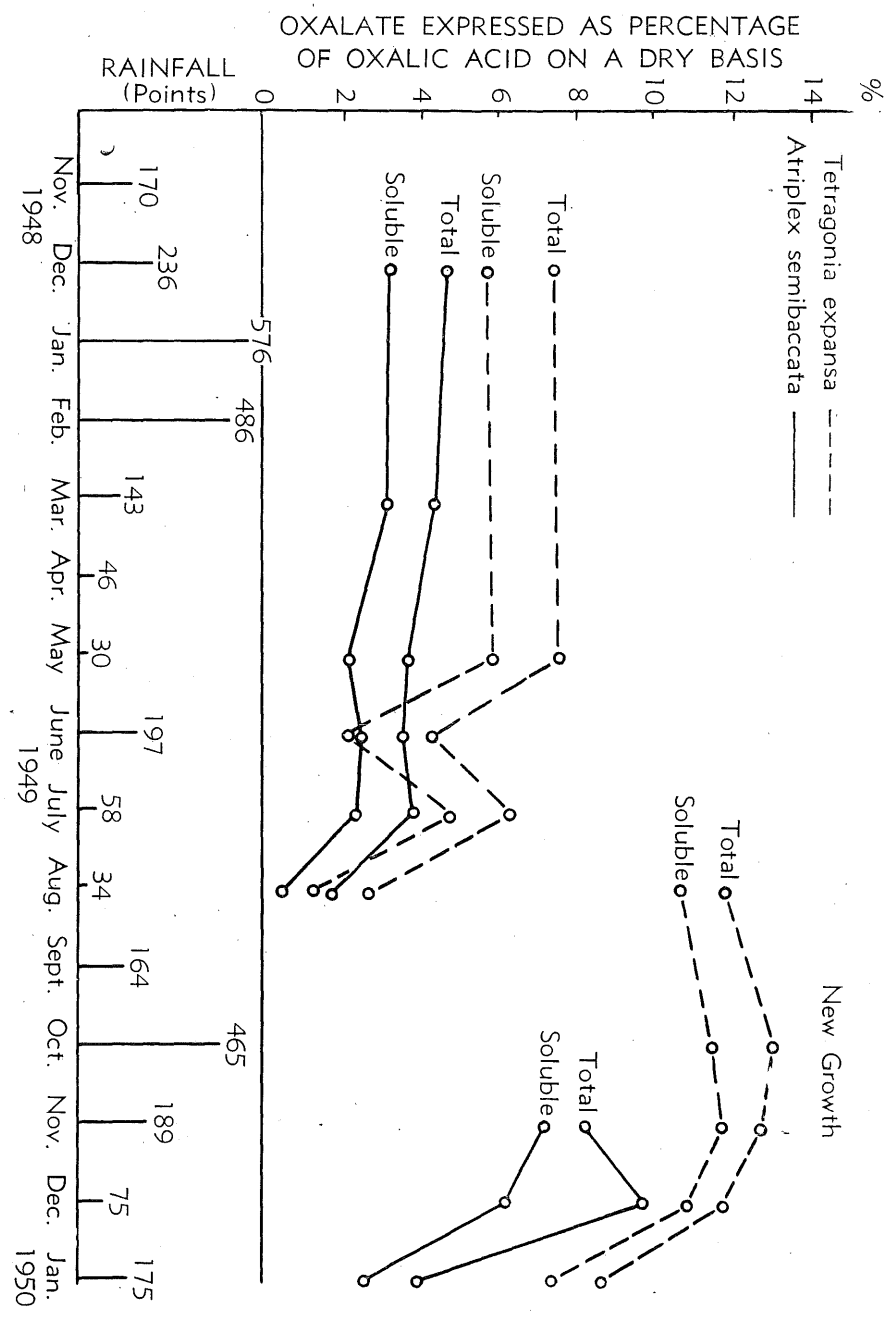

Fig. 1.

Total and Soluble Oxalate in Samples of *Tetragonia expansa* and *Atriplex semibaccata* from a Pasture at Goondiwindi. The monthly rainfall (in points) is also shown.

THE EFFECTS OF OXALATE-RICH PLANTS ON GRAZING ANIMALS.

The effects of oxalate ingestion have been summarized by Rimington and Steyn (1933) as follows:—

"(1) A local inflammation, present even when the acid is administered in dilute solution.

(2) Muscular twitching or tetany, accompanied by other nervous symptoms due to the removal of calcium ions from the system and an upset of the base balance Ca Mg/Na K.

(3) Lowered coagulability of the blood owing to the decrease in calcium ions.

(4) Lesions in the excretory organs, kidneys, etc., owing to the deposition in the cellular substance of hard, crystalline concretions of calcium oxalate."

Losses due to chronic oxalic acid poisoning were described by Bull (1929) in sheep that had grazed seven weeks or more on pastures composed almost entirely of *Oxalis cernua* in South Australia. Some sheep exhibited tetany, but the majority died as the result of extensive nephritis due to the presence in the plant of large quantities of oxalic acid.

Stafford, Franklin and Brown (1937) described acute oxalate poisoning in flocks of lactating ewes that grazed pastures heavily infested with sorrel (*Rumex acetosa*). The symptoms were those of acute hypocalcaemia. Serum inorganic calcium levels in nine affected ewes ranged from 2.45 mg. to 6.51 mg. per 100 ml., and treatment by parenteral injection of calcium gluconate was followed by rapid recovery. The trouble was attributed to the high oxalic acid content of the leaves and stems of the sorrel—up to 0.27 per cent. on green, undried material.

Hypocalcaemia and hypermagnesaemia in wethers that grazed on *Oxalis corniculata* was recorded by the New South Wales Department of Agriculture in 1938 (Hurst, 1942).

The occurrence of hypocalcaemia in sheep fed oxalate-rich plants was studied by the Australian Council for Scientific and Industrial Research (1944, 1945, 1946) and is mentioned as follows in the three Annual Reports cited:—

"Chemical analyses were made of two species of Portulaca and one of Oxalis. The values for total oxalate content ranged from 8·5 to 15·5 per cent. Consumption of these plants was possibly associated with an outbreak of clinical hypocalcaemia in ewes." (1944.)

"Force-feeding experiments on sheep with *Oxalis cernua* (soursob) and *Threlkeldia proceriflora* (soda-bush), both of which are rich in salts of oxalic acid, showed that they may cause an acute hypocalcaemia which can be cured by injection of calcium gluconate. In the case of soda-bush poisoning, a sheep thus cured of the acute symptoms developed lesions in the urinary tract." (1945.)

"A force-feeding experiment with locally grown *Oxalis cernua* (soursob) confirmed the previous finding that severe hypocalcaemia can be induced by as little as 600 grams of the undried plant, owing to its high oxalate content." (1946.)

Talapatra, Ray and Sen (1948) showed that the high level of soluble oxalate in a ration of paddy straw fed to cattle interfered with calcium assimilation.

Mortality in stock has occurred occasionally in Queensland as the result of ingestion of oxalate-rich plants—viz., *Portulaca oleracea, Threlkeldia proceriflora, Trianthema portulacastrum* and *Salsola kali.* Observations on the role of ingested oxalate in the aetiology of urinary calculi in sheep will be published in a separate paper. The following remarks are therefore confined to acute oxalate poisoning.

Portulaca oleracea (Pigweed).

This species has occasionally been suspected of poisoning sheep, but the evidence has been considered inconclusive. The fresh green plant was fed to three experimental sheep at the Animal Health Station, Yeerongpilly, in 1940 (White, Harvey and Mathams, unpublished) as follows:—

Wether No. 75, weight 65 lb., was fed at the rate of 1,400 g. per day during the first week, increasing gradually to 1,750 g. per day during the sixth and seventh weeks, after which it died; the lesions were emaciation and chronic intoxication.

Lamb No. 85, weight 44 lb., was fed 1,000 to 1,200 g. per day for 8 weeks.

Lamb No. 86, weight 49 lb., was fed 1,000 to 1,200 g. per day for 9 weeks.

The plant fed to Nos. 75 and 85 contained 6.1 per cent. total oxalate, and that fed to No. 86 contained 3.5 per cent. total oxalate (soluble oxalate was not determined). The serum calcium levels of all three sheep remained within the normal range. Lambs Nos. 85 and 86 lost some weight but showed no other ill effects, either before or after they were sacrificed for autopsy.

More recently there has been substantial field evidence that pigweed of high oxalate content can poison hungry sheep that gorge the plant.

In June 1950, deaths in a mob of 30 yearling rams were investigated at Longreach by Mr. R. B. Young (Senior Sheep and Wool Adviser). After a 24-hour journey by road and rail transport, the rams were untrucked and confined in the railway yards at 11 a.m. At 5 p.m. the same day they appeared healthy, but at 7 a.m. next morning seven were dead. The post-mortem findings (viz., acute congestion of subcutis and viscera, particularly the kidneys, and tympanites of the rumen) were consistent with acute oxalate poisoning. The bulk of the ingesta in the rumen was pigweed (stems, leaves, fruits and seeds); a much smaller amount of *Trianthema portulacastrum* (see page 328) was also present. The yards in which the rams were confined contained a great deal of pigweed, together with some harmless weeds. A sample of the pigweed sent to the laboratory contained 7.4 per cent. soluble and 9.3 per cent. total oxalate. It was concluded that death was due to acute oxalate poisoning.

A similar condition occurred in a mob of 268 rams which were examined at Cunnamulla in April 1952 by Mr. A. W. Grummitt (Inspector of Stock). The rams were unloaded after a 25-hour journey into yards containing a heavy growth of button grass and pigweed. The four affected sheep showed unsteady gait and hypersensitivity. Two died about two hours after they were first observed sick, and two others recovered after treatment with calcium borogluconate. At autopsy, enteritis and congestion of the lungs were seen. Analyses of ingesta sent to the laboratory showed the following amounts of total oxalate:—

Rumen content	2.16%
Small intestine content	2.11%

Samples of mature pigweed (after flowering) were collected subsequently from the yards. The plant was identified as probably *Portulaca oleracea,* but possibly *Portulaca intraterranea,* because specific identification is not possible in the absence of good flowering material. These samples contained oxalate as follows:—

	Soluble. %	Total. %
Sample No. 1	5·1	7·9
Sample No. 2	4·6	7·7

A week later 12 out of a mob of 369 mixed fat cattle died in the same yards. Inspector Grummitt reported that the cattle had been four days without feed when they were unloaded into the yards. No sick animals were examined. The one animal available for autopsy showed haemorrhages of the mucosa of the abomasum and intestine. Analysis of a sample of rumen content showed that it contained 1.7 per cent. of total oxalate.

A fourth instance of acute oxalate poisoning due to the ingestion of *Portulaca oleracea* was investigated in 1952 by Mr. R. B. Young (Senior Sheep and Wool Adviser) and is best presented by quoting from his report accompanying specimens sent to the laboratory.

"A flock of 2,100 ewes in good condition and due to lamb in four weeks were yarded for the night preparatory to crutching. Next morning they were released hungry into a paddock not used for some time and rich in pigweed and other herbage. In a few hours 100 ewes were sick, showing pallor and later cyanosis of visible mucosae, paralysis of hindquarters and bloat. They tried to rise when disturbed but soon went down again.

"Five ewes died and the remainder recovered, although it was feared at one stage that all might die. Forty ewes were treated with calcium borogulconate, and 20 were drenched with sodium thiosulphate, but recovery occurred equally in untreated and treated sheep.

"Autopsies revealed intense congestion of the viscera. The paunches were very full and contained much gas and a great deal of pigweed."

Samples of pigweed and dried stomach content sent to the laboratory were analysed for total oxalate, with the following results:—

Portulaca oleracea	10.75%
Ingesta	4.77%

The presence in the stomach of much pigweed and a high level of oxalate is considered to confirm the field diagnosis of acute oxalate poisoning due to the ingestion of pigweed.

Salsola kali (Soft Roly Poly).

This annual or perennial herb is abundant in western Queensland. The mature plant is dry and easily broken, so it is carried by the wind and becomes piled against fences and other obstacles. Although the mature plant is quite unattractive to stock, the immature stage is heavily grazed by sheep and cattle.

Zellner (1927) found that *Salsola kali* is rich in potassium salts and also contains appreciable oxalic acid. Hurst (1942) stated that the plant had been suspected of causing mortality in cattle in New South Wales, but no particulars were given. McClymont (1947) listed it as one of the common weeds in New South Wales which are rich in oxalates.

The plant is suspected to have caused mortality in stock on several occasions in Queensland, shown in the records and reports of officers of the Department as follows:—

1939—In pigs and calves at Chinchilla.

1940—In hungry cattle at Hughenden.

1942—The loss of 800 out of several thousands of sheep that travelled on stock routes in the Julia Creek district was attributed to this plant.

1947—Mortality in cattle at Pittsworth was attributed to young *Salsola kali* three to five inches high, which was heavily grazed. The cattle had just been untrucked after travelling from a dry area.

The toxicity of *Salsola kali* was tested at the Animal Health Station, Oonoonba, by Mr. R. E. Churchward (Veterinary Officer) in 1940. The following particulars are from his unpublished report.

One pound of plant (stage of growth not stated) was extracted with one litre of water for 24 hours; the fluid was then expressed and administered by stomach tube to sheep weighing 80-90 lb. The results were:—

SHEEP No. 19.

1st day—extract from 1 lb. given

2nd day—extract from 1 lb. given

7th day—extract from 2 lb. given

8th day—found dead.

Autopsy revealed intense congestion of the mucosa of the abomasum and duodenum. The kidneys were soft with petechiae in the cortex, and the capsule stripped easily. Subcutaneous blood vessels were engorged, and the blood throughout the body was dark and not completely clotted.

SHEEP No. 16.

1st day—ate 1 lb of freshly chaffed *Salsola kali.*

2id day—aqueous extract from 2 lb. of plant.

3rd day—refused freshly chopped plant.

4th day—refused to eat fresh plant; appeared normal; discharged.

SHEEP No. 18.

1st day—aqueous extract of 2 lb. *Salsola kali.*

2nd day—aqueous extract of 2 lb. *Salsola kali.*

3rd day—apparently normal.

4th day—appeared normal; discharged.

It would appear that at the time of these observations the possibility of the toxicity of *Salsola kali* being due to its oxalate content was not considered. The findings on sheep No. 19 are consistent with death from acute oxalate poisoning. It is evident, too, from the results shown in Table 1 that the amount of soluble oxalate in immature *Salsola kali* (4—10 per cent.) would be likely to cause acute oxalate poisoning, particularly when heavily grazed by hungry stock.

Trianthema portulacastrum (Black Pigweed).

The loss of four of a group of 30 fat cattle at Emerald was investigated in February 1952, by Mr. J. T. Littleton (Inspector of Stock). The cattle were yarded for about three days and then grazed on a heavy stand of *Trianthema portulacastrum* and some *Portulaca oleracea.* Symptoms exhibited were diarrhoea, dyspnoea and salivation. The gait was short and the head was held forward with tongue protruded. Later the faeces were scanty. The animals died in a sleeping position. Autopsy revealed inflammation of the abomasum and duodenum. Pigweed was present in the rumen.

Samples of the two pigweeds obtained from the area contained oxalate as follows:—

	Soluble. %	Total. %
T. portulacastrum	7·7	9·6
P. oleracea	5·0	8·3

Threlkeldia proceriflora (Soda Bush).

Heavy stands of this weed occur at times in central-western Queensland, particularly on overgrazed areas such as stock routes and reserves. Field and experimental evidence on its toxicity to sheep was reported by Legg and Francis (1939). They described mortalities that occurred when hungry sheep were allowed to graze heavy stands of the plant. They found that 1 lb. of fresh plant killed a wether which had been starved for 24 hours. The force-feeding experiments mentioned earlier (Australia, Council for Scientific and Industrial Research, 1946) indicate that the toxicity of soda bush is due to its oxalate content.

Instances of poisoning by soda-bush have not been investigated by us. The oxalate content of one of the samples examined was rather low (3.6 per cent. total), but the second was quite high (6.2 per cent. soluble and 8.6 per cent. total) and would be dangerous to hungry stock that gorged on it.

Bassia echinopsila (Red Burr).

This is one of the common winter herbage species of central-western Queensland. It is extensively grazed by sheep wherever it occurs. Only four samples have been examined for oxalate (Table 1). One sample (from Winton in September 1952) consisted of plants 1½-6 in. high at the early fruiting stage and contained 5.1 per cent. soluble and 7.5 per cent. total oxalate. Another sample contained 7.9 per cent. total oxalate but only a trace of soluble oxalate. The remaining two samples were older plants and did not contain appreciable oxalate.

The only record of *B. echinopsila* having been suspected of causing poisoning in stock is a report by Mr. M. N. S. Jackson (Senior Sheep and Wool Adviser)*. In a mob of 2,000 lambing ewes 50 died in January 1948 when they were held for 24 hours prior to crutching in a paddock in the Winton district containing a heavy stand of red burr. The symptoms and post-mortem findings were consistent with acute oxalate poisoning, and were in fact noted as being similar to those of poisoning with *Threlkeldia proceriflora*. At the time of these field observations it was not appreciated that red burr may at times contain a high level of soluble oxalate.

Tetragonia expansa (New Zealand Spinach).

It is shown in Fig. 1 that samples of this species range from as low as 2.9 per cent. total oxalate in mature plants to the very high figure of 12.0 per cent. soluble and 13.1 per cent. total oxalate in immature plants. However, there is no record of its having come under suspicion as a cause of mortality in sheep or cattle in Queensland. This is probably due to the fact that it is palatable to sheep only when it is mature and rather dry (S. L. Everist, personal communication, 1952).

* We are indebted to Mr. W. D. Francis, Government Botanist, for drawing our attention to this record.

DISCUSSION.

Among the 17 grasses examined, *Panicum antidotale* was the only one with a significant oxalate content (3·5 per cent. soluble and 4·9 per cent. total). Talapatra, Ray, Kehar and Sen (1942) listed nine grass species in which they found only small quantities of oxalic acid, and in addition they reported the following as containing significant amounts:—

	Anhydrous Oxalic Acid (Dry Basis).	
	Total.	Soluble.
	%	%
Paddy straw—		
No. 1	1·46	1·25
No. 2	1·60	1·35
Napier grass (*Pennisetum purpureum*)—		
Early cut	3·05	2·04
Dead ripe	0·65	0·40
Guinea grass (*Panicum maximum*)—		
Early cut	2·00	1·10
Dead ripe	0·80	0·25

They considered these levels of oxalic acid to be high, particularly in plants in the early stages of growth. The amounts are higher than those in most of the grasses we examined, but they are much lower than the amounts in some of the common Queensland herbage (forb) species—e.g., the saltbushes (*Atriplex muelleri* and *Atriplex semibaccata*), *Chenopodium hubbardii*, *Portulaca oleracea*, *Salsola kali*, and *Trianthema portulacastrum*.

Talapatra, Ray and Sen (1948) showed in India that the high level of oxalate in a ration of paddy straw interfered with the calcium assimilation of cattle. They showed further that the soluble oxalate was the fraction that interfered with calcium metabolism, while the insoluble fraction (probably in the form of calcium oxalate) was excreted unchanged in the faeces. It would seem, therefore, that the toxicity of an oxalate-rich plant is due chiefly to its content of soluble oxalate.

The experiments of Fleming (1928) with *Sarcobatus vermiculatus* (greasewood) in Nevada, U.S.A. provide valuable information on the amounts of plant and the circumstances required to cause acute oxalate poisoning in sheep. The analyses reported on six samples of the plant showed 11·40 per cent. to 15·39 per cent. anhydrous oxalic acid on a moisture-free basis, but the method used would be likely to give figures 2–3 per cent. too high. It is therefore probable that the plant Fleming used for feeding experiments contained about 10 per cent. total oxalate. (The soluble oxalate content was not reported).

The results of 36 feeding tests with leaves and green stems of greasewood, in which the amounts of plant shown were force-fed to sheep in 30–60 minutes, are summarized as follows:

Result.	Number of Feeding Tests.	Amount of Plant Fed in Lb. per 100 Lb. Liveweight.
Death	36	4·50–8·69 (mean 5·61)
Sickness and recovery	9	3·53–6·11 (mean 5·06)
No symptoms	11	1·87–5·02 (mean 3·88)

The smallest dose that caused symptoms was 3·53 lb. per 100 lb. liveweight, but in three tests more than 4·00 lb. and in two tests more than 5·00 lb. failed to cause any symptoms. Fleming remarked that this showed that "the individuality of the animal and its condition influence the degree to which it is subject to this form of poisoning." He did not mention that variations in oxalate content of different samples of plant might also be important. It can be assumed, however, that the fatal dose of greasewood is about 5·00 lb. per 100 lb. liveweight when it is consumed within an hour.

Two ewes were fed greasewood mixed with the daily ration of grasses, clovers and weeds at the rate of 4·00 and 5·00 lb. per 100 lb. liveweight, and no ill effects were produced. In a third series of experiments, greasewood equivalent to 5·0, 6·3, 5·88 and 6·69 lb. per 100 lb. was fed in two, nine, three and three force-feedings during the day (9 a.m. to 5 p.m.) No ill effects were produced. Fleming therefore concluded that "sheep become poisoned by greasewood as a result of eating the leaves and green stems almost exclusively in a quantity approximating the stomach capacity during a relatively short time."

These experiments are consistent with the observations recorded above in connection with poisoning by *Portulaca oleracea, Salsola kali, Trianthema portulacastrum* and *Threlkeldia proceriflora*—viz., that travelling or hungry stock are particularly apt to be affected. Such stock often eat in a short time large quantities of plants that local stock eat in only small quantities. Further, acute poisoning may be apt to occur in hungry stock because of more rapid absorption of oxalate.

The natural pastures in western Queensland usually contain a great variety of plant species; so, except in special circumstances, such as those encountered by travelling stock, a large quantity of any single species is not likely to be eaten by grazing animals. It has been frequently observed also that stock accustomed to pastures containing oxalate-rich plants do not suffer acute poisoning—perhaps their grazing habits are such that large amounts of oxalate are not ingested at one time. The instances of *Oxalis cernua* poisoning described by Bull (1929) in South Australia and of sorrel poisoning described

by Stafford, Franklin and Brown (1937) in New Zealand occurred in sheep grazing heavy, almost pure, stands of these weeds which had developed on cultivation paddocks.

The most acute manifestation of poisoning by oxalate-rich plants would appear to be a poisoning by oxalate *per se,* while in the less severe manifestation hypocalcaemia or alkalosis may be the prominent feature. In animals whose calcium metabolism is delicately balanced, such as the lactating ewes described by Stafford, Franklin and Brown (1937), hypocalcaemia is especially evident.* In many field outbreaks both manifestations occur. Recovery from acute oxalate poisoning entails the risk of subsequent symptoms attributable to chronic lesions in the urinary tract (Australia. Council for Scientific and Industrial Research, 1946).

Little information is available on the toxic doses of oxalic acid and its salts for sheep and cattle. New Zealand workers (New Zealand Department of Agriculture, Animal Research Division, 1952) have reported on the toxicity of sodium oxalate for cattle. They dosed four cows by mouth with 100 g., 200 g., 400 g. and 600 g., respectively, in five equal doses in two hours. The results were:—

100 g.—No effect.

200 g.—Symptoms which were alleviated by three injections of calcium within 10 hours.

400 g. and 600 g.—Died in convulsions within four hours of the first drench.

In the three affected cows, the most marked feature was the rapid drop in serum calcium.

According to Frohner (1919), a sheep (weight 35 kg.) that received 25 g. of oxalic acid—i.e. 0·7 g. per kg.—in water (concentration not mentioned) died in four hours.

M. White, J. M. Harvey and R. H. Mathams (1940, unpublished) examined the toxicity for sheep of sodium oxalate given by mouth in 2 per cent. aqueous solution. Their results (Table 2) show that one lamb given 1 g. sodium oxalate per kg. body weight died of acute oxalate poisoning. One lamb showed no ill effects from a dose of 0.5 g./kg. per day for 23 weeks, while another lamb given 0·37 g./kg. per day died in the 22nd week of the experiment.

* Field observations indicate that clinical hypocalcaemia (which responds to calcium therapy) often occurs in western Queensland when pregnant or lactating ewes are mustered and confined for 24-48 hours for operations such as crutching or shearing. The trouble is more prevalent during good winter seasons when herbage is abundant (K. J. Astill, personal communication, 1952). In addition to exercise and fasting, which have been shown experimentally to precipitate clinical hypocalcaemia in ewes (Franklin, 1948a, 1948b), heavy feeding on oxalate-rich herbages might also play a part in these outbreaks.

Table 2.

TOXICITY OF SODIUM OXALATE GIVEN ORALLY IN 2% AQUEOUS SOLUTION TO SHEEP 50—60 LB. LIVEWEIGHT.

(After White, Harvey and Mathams, 1940, unpublished.)

Lamb No.	Dose Rate per Day g./kg.	Duration of Treatment.	Result.
135	1·0	Once only	Died less than 24 hours
88	1·0	2 days	Died
90	1·06	6 days	Killed—moribund
89	1·0	11 days	Died
140	0·5*	23 weeks	Negative
141	0·37*	22 weeks	Died
142	0·32*	23 weeks	Negative
143	0·28*	23 weeks	Negative

* Divided into four doses each day.

It is evident that the figures given in Table 1 are a general guide only to the oxalate content of a plant. Oxalate content is highest in immature plants, and it varies also with rainfall, and probably also with soil and other environmental factors. Diurnal periodicity in the oxalic acid content of the leaves of *Oxalis cernua* and many desert succulent plants has been mentioned by Clarke (1934). We have noticed, too, that when plant samples have been dried slowly, the oxalate content has usually been lower than would be expected, but we have no exact data on this point. Again, we have observed that specimens that reached us in a mildewed condition have shown lower amounts of oxalate, particularly soluble oxalate, suggesting that some of it may be destroyed by fungi.

There is also another difficulty that arises in attempting to assess the oxalate intake of sheep. As the plant matures and becomes lignified, the soluble oxalate content decreases, so analysis of the entire plant probably does not give a true indication of the oxalate consumed by an animal that usually selects the young, more tender parts of the plant.

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