SEGES

CALCULATING FERTILIZER SALT INDEX AND EFFECTS OF SOIL SALT CONCENTRATION ON CROP GROWTH

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Saltindekset af en gødning kan anvendes som et mål for den saltkoncentration, som gødningen inducerer i jordopløsningen.

ABSTRACT

Saltindekset af en gødning kan anvendes som et mål for den saltkoncentration, som gødningen inducerer i jordopløsningen. Saltindeket gør det muligt at klassificere en specifik gødning i forhold til andre vedrørende den osmotiske effekt og skildrer om gødningen vil være mere tilbøjelig til at skade afgrøder. Afgrøder på tidlige vækststadier er mere følsomme over for salt stress i forhold til planter på senere vækststadier og varierer signifikant i deres tolerance over for salte. Hvede og majs har en moderat tolerance mens hestebønner og grøntsager er meget følsomme over for øgede saltbetingelser. Saltindeks i gødning er mest hensigtsmæssigt anvendt i forbindelse med dyrkning af sandjord som følge af den øgede evne til at skade gennem overdreven osmotiske tryk af jordopløsningen. N og K gødninger har normalt højere saltindeks-værdier end P gødningen, idet phosphater har relativt lille ind virkning på det osmotiske tryk af jordopløsningen.

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Most commonly used fertilizer materials are highly soluble salts, which separate in the soil solution following fertilizer application. The salt concentration of soil can be detrimental for seeds and plants because it increases the osmotic potential of the soil solution, making it harder to extract soil water required for growth. In cases of a high soil salt concentration (usually when a fertilizer with a salt index >20 is applied) plasmolysis can occur, which is when water starts moving out of the plant roots back into the soil and potentially causing plant death (Leonard, 1986). The salt index (SI) of a fertilizer can be used as a measure of the salt concentration that fertilizer induces in the soil solution (Mortvedt, 2001). The SI can classify the fertilizer with respect to others regarding osmotic effect and depicts which fertilizers will be most likely to injure crops (Rader et al., 1943). Rader *et al* (1943) points out that it is possible to formulate two mixed fertilizers of the same grade, for example 4-8-4, and one will increase the osmotic pressure of the soil solution four times as much as the other when equal amounts are applied.

One reason for this variance may be due to the difference in placement of the two mixtures. For example, coarse-textured soils with low organic matter content have a low cation exchange capacity (CEC), meaning a reduced ability to react with fertilizer, compared to fine-textured soil (with a high CEC), which means that the concentration of fertilizer salts in the soil solution remains high (Reid, 2006). Thus, on sandy soils with low organic matter, plant injury due to fertilizer application is a greater issue, especially in dry springs. Other factors influencing the osmotic pressure produced in the soil solution by a given salt application are the amount of moisture in the soil, base exchange and other sections into which the added salt may enter, temperature and the varying colloid content and type of colloid (Radar et al., 1943).

A SI is defined as the ratio of the increase in osmotic pressure produced by the addition of fertilizer material to that produced by the same weight of sodium nitrate and, to give whole numbers, multiplied by 100 (Rader et al.,1943). The SI of sodium nitrate ($NaNO_3$) is defined as 100, therefore, fertilizer materials with a SI greater than 100 produces osmotic potential greater than an equal weight of sodium nitrate. All fertilizers are compared to $NaNO_3$ because it is 100% water soluble and Radar *et al* (1943) originally used $NaNO_3$ as a comparison when developing the concept of the SI. This is expressed by the following equation reproduced from Rader et al (1942):

$$SI = \frac{Osmotic\ Pressure_{Fertilizer\ material}}{Osmotic\ Pressure_{NaNO_3}} \times 100$$

N and K fertilizers usually have higher SI values than P fertilizers Reid (2006) and salts from N and K compounds will move upwards as the soil dries out and will injure the seeds or young roots (Leonard, 1986). In other words, phosphates have relatively little effect on the osmotic pressure of the soil solution.

CALCULATING SI OF A MIXED FERTILIZER

The SI of a mixed fertilizer containing N, P and K is the sum of the partial SI per unit (20 lbs) of plant nutrient times the number of units due to each component in the formulation. Tables 1-3 are a step-by-step example of how the salt index is calculated for formulation 7-21-7. First, list the material, grade and weight for each component (Table 1, Columns 1-3), then determine nutrient units (Columns 4-6) by multiplying the weight of each component by its nutrient content and dividing each result by 20 (Table 1). The nutrient content is divided by 20 because 20 pounds, 1 percent of a ton, is commonly used in fertilizer calculations.

Table 1. Calculation example of 7-21-7, step 1.[a]

Material	% Nutrient	lbs of material per ton of formulation	Nutrient units			Salt index	
			N	P_2O_5	K_2O	Per unit (20 lb) *	in formulation
1	2	3	4	5	6	7	8
			(Col 3 x Col 2) /20				(Col 4 + Col 5 + Col 6) x Col 7
10-34-0	10% N, 34% P_2O_5	1.235	6,2	21	-		
UAN	28% N	57	0,8	-	-		
KCl	62% K_2O	226	-	-	7		
Water		482	-	-	-		
Formulation		2.000	7	21	7		

List the SI per plant nutrient unit in each component (Table 2, Column 7).

Table 2. Calculation example of 7-21-7, step 2.[a]

Material	% Nutrient	lbs of material per ton of formulation	Nutrient units			Salt index	
			N	P_2O_5	K_2O	Per unit (20 lb) *	in formulation
1	2	3	4	5	6	7	8
			(Col 3 x Col 2) /20				(Col 4 + Col 5 + Col 6) x Col 7
10-34-0	10% N, 34% P_2O_5	1.235	6,2	21	-	0,46	
UAN	28% N	57	0,8	-	-	2,25	
KCl	62% K_2O	226	-	-	7	1,94	
Water		482	-	-	-	-	
Formulation		2.000	7	21	7		

The SI of a mixed N, P, and/or K formulation is the sum of the SI values of its' individual components (Table 3, Column 8). The SI per ton of a dry, mixed or liquid formulation containing N, P and/or K is obtained by multiplying the adjusted salt index of plant nutrients (the SI per unit of nutrients).

Table 3. Calculation example of 7-21-7, step 3.[a]

Material	% Nutrient	lbs of material per ton of formulation	Nutrient units			Salt index	
			N	P_2O_5	K_2O	Per unit (20 lb) *	in formulation
1	2	3	4	5	6	7	8
			(Col 3 x Col 2) /20				(Col 4 + Col 5 + Col 6) x Col 7
10-34-0	10% N, 34% P_2O_5	1.235	6,2	21	-	0,46	12,4
UAN	28% N	57	0,8	-	-	2,25	1,8
KCl	62% K_2O	226	-	-	7	1,94	13,6
Water		482	-	-	-	-	-
Formulation		2.000	7	21	7		**SI = 27,8**

[a]Tables 1-3 are reproduced from Mortvedt (2001)'s explanation of calculating salt index.

Fertilizers with a SI greater than 20, such as the above example, should not be seed-row applied. The Salt Indexes for common inorganic fertilizers are listed in Table 4.

Table 4. List of salt indexes for commonly used inorganic fertilizers

Carriers	Fertilizer	Formula	Salt Index		Reference
			Salt Index	per unit of nutrients* (Partial Salt Index)	
Nitrogen/ Sulfur	Ammonia	82-0-0	47	0,57	(Rader et al., 1943)
	Sodium nitrate	17-0-0	100	-	(Rader et al., 1943)
	Ammonium nitrate	35-0-0-0	104	3,06	(Rader et al., 1943)
	Ammonium sulfate	21-0-0-24	68,3	3,25	(Mortvedt, 2001)

	Ammonium thiosulfate	12-0-0-26	90,4	7,53	(Mortvedt, 2001)
	Urea	46-0-0-0	75,4	1,62	(Mortvedt, 2001)
	UAN	28-0-0-0	63	2,25	(Mortvedt, 2001)
	UAN	32-0-0-0	71	2,22	(Mortvedt, 2001)
Phosphorus	APP	10-34-0-0	20	0,46	(Mortvedt, 2001)
	Diammonium phosphate	18-46-0-0	29,2	0,46	(Mortvedt, 2001)
	Monoammonium phosphate	11-52-0-0	26,7	0,41	(Mortvedt, 2001)
	Diammonium phosphate	21-23-0	34,2	1,61	(Rader et al., 1943)
	Monoammonium phosphate	12-27-0	29,9	2,45	(Rader et al., 1943)
	Monoammonium phosphate	46,6%	75,4	1,618	(Rader et al., 1943)
	Diammonium phosphate	13,8%	73,6	5,336	(Rader et al., 1943)
	Monoammonium phosphate	61,7%	29,9	0,485	(Rader et al., 1943)
	Diammonium phosphate	53,8%	34,2	0,637	(Rader et al., 1943)
	Superphosphate	0-16-0	7,8	0,487	(Rader et al., 1943)
	Superphosphate	0-18-0	7,8	0,433	(Rader et al., 1943)
	Superphosphate	0-20-0	7,8	0,39	(Rader et al., 1943)
	Superphosphate	0-45-0	10,1	0,224	(Rader et al., 1943)
	Superphosphate	0-48-0	10,1	0,21	(Rader et al., 1943)
	Superphospate (single)	0-8-0	7,8	-	(Bunt, 1988)
	Superphospate (triple)	0-20-0	10	-	(Bunt, 1988)
Potassium	Monopotassium phosphate	0-52-35-0	8,4	0,10	(Mortvedt, 2001)
	Potassium chloride	0-0-62-0	120	1,94	(Mortvedt, 2001)
	Potassium sulfate	0-0-50-18	42,6	0,85	(Mortvedt, 2001)

	Potassium thiosulfate	0-0-25-17	68	2,72	(Mortvedt, 2001)
Liquid Solutions	-	2-20-20[a]	7,2	0,17	(Fernández, 2010)
	-	3-18-18[a]	8,5	0,22	(Fernández, 2010)
	-	6-24-6[a]	11,5	0,32	(Fernández, 2010)
	-	6-30-10[a]	13,8	0,30	(Fernández, 2010)
	-	9-18-9[a]	16,7	0,48	(Fernández, 2010)
	-	4-10-10[c]	27,5	1,18	(Fernández, 2010)
	-	7-21-7[c]	27,8	0,79	(Fernández, 2010)
	Ammonium polyphosphate	10-34-0[b]	20	0,46	(Fernández, 2010)

[*] One unit equals 20 lb.
[a] Formulated using potassium phosphate as the K source.
[b] Use with caution for seed-row placement
[c] Not recommended for seed-row placement.

The osmotic pressure increase potential of 4 commonly used fertilizers in Denmark are listed in Table 5. Triplesuperfosfat 20 has the least potential for increasing osmotic pressure after application because is composed of phosphate, which, as previously stated, has relatively little effect on the osmotic pressure of the soil solution.

Table 5. List of potential for osmotic pressure increase based on fertilizer formula (from greatest to least).

Fertilizer	Formula	Osmotic pressure increase potential
NP	26-6-0 m S, B, Zn (Yara)	Greatest potential
NP	18-20-0 (diammoniumfosfat)	
NP	12-23-0 (monoammoniumfosfat)	
Triplesuperfosfat 20	-	Least potential

CROP TOLERANCE TO SALTS

Another method in determining SI is through electrical conductivity. Laboratories can perform a soil analysis to measure the soluble salt content of soils through electrical conductivity tests, where they measure the electrical conductance in 1% fertilizer solution, instead of the osmotic pressure in the soil solution. The higher the electrical conductivity, the higher the salt content in the soil. Table 6 is a list of standard electrical conductivity measurements, measured in millimhos, and the required salt tolerance of the crop, based on the electrical conductivity measurements.

Table 6. Soluble salt content of soils and required crop salt tolerance[a]

Electrical Conductivity (Millimhos)	
< 2	No adverse effect
< 8	Crop must be moderately salt tolerant
8 - 16	Cop must have good salt tolerance
> 16	No profitable cropping possible

[a] Reproduced from Leonard (1986)

In a review by Zörb et al (2019) that discusses the processes that limit plant growth and yield in saline conditions, they discuss how salinity can cause crop yield losses, even though the effects of salinity may not be noticeable. They found that wheat and maize had a 10% yield decrease at soil extract salinity (EC_e) levels of 2.5 (7.2 dS m^{-1}) and a 50% yield decrease at EC_e levels of 5.5 (13 dS m^{-1}).

CROP TOLERANCE TO SALTS

A crop's salt tolerance and sensitivity depends on its ability to extract water and nutrients from saline soils, as well as avoiding excessive tissue accumulation of salt ions (Zörb et al., 2019). Crop tolerance to increased osmotic potential from fertilizer near the seed varies significantly (Table 7). As shown in Table 7 wheat is moderately tolerate of high-salt conditions, with soybeans and vegetables being the most sensitive (Reid, 2006). The results from a study by Katerji *et al* (2000) confirm the salt tolerance of the crops listed in Table 7, where it was found that sugarbeet and durum wheat were highly salt tolerate, whereas soybean was only moderately tolerant. Furthermore, Katerji *et al* (2000) concluded that maize, potato and sugar-beet were slightly less salt tolerate compared to wheat. According to Ayers and Westcot (1985), other moderately sensitive crops include alfalfa and clover.

Table 7. Crop tolerance to salts[a]

Crop	**Relative sensitivity**
Wheat	Least sensitive[b]
Corn	↓
Forage Legumes	↓
Soybean and Edible bean (dry or snap)	↓
Vegetables	Most sensitive

[a] Reproduced from Reid (2006).

[b] Least sensitive does not mean that the crop is not sensitive to salt.

Fertilizers that are most suitable for a seed row application are those with a low salt index, high water solubility and contain N, P, K and S with a relatively high P content.

FERTILIZER PLACEMENT

Fertilizer placement recommendations vary depending on the crop and is influenced by the crop tolerance to increased osmotic pressures of the soil solution. Oil-seed crops, such as soybeans, have a very low tolerance to seed-row application of fertilizer, compared to wheat which is more tolerant of high salinity conditions (Mortvedt, 2001). The recommendation for corn in direct seed contact is 10-20 lbs/acre of N + K_2O, when applied to formulations using KCl as the source of K (Mortvedt, 2001). If potassium phosphate was used as the source of K instead of KCl, it would not be accurate because potassium phosphate has a lower SI value than KCl (Table 4). Seed-row application of NH_3 should be avoided because it can result in poor germination. Generally, fewer problems are encountered using fluid fertilizers as seed-row fertilizers, compared to granular, due to less soil water required, salts mainly dissolve in fluid formulations and fluid fertilizers feasibly produce a lower osmotic pressure in the soil solution (Mortvedt, 2001).

CONCLUSION

Crops at early growth stages are more sensitive to salt stress compared to plants at later growth stages, and, therefore, it is important to understand the salt concentration of the fertilizer that will be applied. The SI can be used to determine the probable effects of different fertilizers or fertilizer constituents upon the osmotic pressure in the soil solution, and therefore, possible crop injury. The SI of fertilizers is most appropriately applied in connection with the management of sandy soils, due to their increased ability to injury through excessive osmotic pressure of the soil solution. For a fertilizer containing more than one nutrient, the SI can be calculated by the sum of the salt index of each component per unit (20 lb) of plant nutrient multiplied by the number of unites in that formation. The SI can also be established by performing a soil analysis to determine the electrical conductivity, which is a current method used by some laboratories. Crops vary significantly in their tolerance to salts, with wheat and maize being moderately tolerate and soybeans and vegetables being very sensitive to increased salt conditions. Fertilizers with an SI ≤ 20 are safe to apply in-furrow next to the seed and fertilizers with an SI > 20 should not be used in seed-placed application.

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