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Influence of ammonium and nitrate salts on the bioelectric potential of oat (*Avena sativa* L.) leaves

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Abstract

The paper concerns the influence of various forms of nitrogen on the bioelectric potential of leaves of oats growing under different light conditions. The measurements performed demonstrated differences in the bioelectric potential of leaves on plants growing on an ammonium or nitrate substrate. On the ammonium substrate the potential is more negative and the differences are wider at higher light intensities. Analyses of potassium and chlorophyll content in the leaves showed no direct correlation between the potential value and potassium content, whereas an increase in chlorophyll content was associated with an eletronegative potential in the leaves.

INTRODUCTION

In the elucidation of problems of mineral plant nutrition investigations seem promising taking into account measurements of the bioelectric potential of the studied plants (D a i n t y, 1962; H i g i n b o t h a m, 1967). Information obtained in these measurements is the more valuable since it is obtained without injury to the plants, thus without disturbing the system under study. A number of authors dealing with the problem of plant nutrition with various forms of nitrogen mention significant differences in the growth, development, mineral salts uptake, photosynthesis and respiration of plants growing on substrates with ammonium salts or nitrates (G u m i ń s k i et al., 1957; S t a b r o w s k a, 1959; K i r k b y, M e n g e l, 1967; H o f s t r a, K o c h - B o s m a, 1970; Z a j ą c z k o w s k a, 1973). Since the response of plants to different forms of nitrogen in the nutrient solution differs, studies were undertaken to establish whether these differences are reflected in the bioelectric potential of the plants. The value of this potential depends on the potassium content in the cells (Sinyukhin and Vyskrebentseva, 1967) and metabolic processes, such as for instance photosynthesis, also affect this potential (Andrianov et al., 1965). Investigations were, therefore, undertaken on potassium, phosphorus and chlorophyll content in leaves. In investigations on potassium and chlorophyll content the causes of differences in bioelectric polarity were the aim in view, whereas in the analysis of phosphorus content the main problem was whether the observed polarity is not the cause of activation of the transporting systems as claimed by various authors (Opritov, 1958; Opritov and Zhuravskaya, 1964; Opritov and Michurin, 1973).

MATERIAL AND METHODS

The investigations were performed with the oat variety Flemingsweiss II in water cultures with 5-6 replications (10 plants per jar) at about 25°C with light intensity 3000 and 10 000 lux (15 h illumination per 24 h). The nutrient solution consisted of: (1) nitrate solution (mg/l.); $Ca(NO_3)_2 2H_2O$ — 768, KNO_3 — 101, KH_2PO_4 — 136, $MgSO_4 7H_2O$ — 246 and (2) ammonium solution: $(NH_4)_2SO_4$ — 495, K_2HPO_4 — 174; $MgSO_4 7H_2O$ — 492, $CaSO_4 2H_2O$ — 440, $CaCl_2 6H_2O$ — 360. The elemental composition of the nutrient solution was for the nitrate (mg/l.): N — 105, K — 78, Ca — 130, Mg — 24, P — 31, for ammonium: N — 105, K — 78, Ca — 168, Mg — 48, P — 31. The macroelements (N, P, K) analysed in detail were present in the same amounts in both kinds of nutrient solutions. A modified microelement solution A_4 after Arnon (1938) was added to the solution (mg/l.): 0.5 B, 0.5 Mn, 0.05 Zn, 0.02 Cu, 0.05 Mo and iron in the form of FeEDTA (5 mg Fe/l.). The nutrient solution was adjusted to pH 6.0 with 1 per cent HCl or 1 per cent NaOH. The experiment lasted 3 weeks, and then the bioelectric potential of leaves was measured, their fresh and dry mass was determined as well as potassium content (by flame photometry), chlorophyll (spectrophotometrically) and phosphorus (by the vanadium-molybdenum method). The leaves were numbered according to the date of their growth, the younger the leaf the higher its number. Electric potential was measured with an E-219 Unitra ZRK electronometre on intact leaves not detached from the plant with saturated calomel electrodes ending in a cotton wool strand saturated with 0.1 M KCl touching the leaves.

In view of the electric polarity of the leaves themselves (Ramshorn, 1934) the site of contact of one electrode was always the centre of the leaf, while the second one was immersed in the medium. Fifteen minutes after establishing the contact of the electrode with the leaf the potential value was read at 1-min intervals (usually for 10-15 min) and the potential value which did not change in 3 successive measurements was adopted as correct. According to Parkinson and Banbury (1966a) and Parkinson (1966b), the potential stabilises after 15-20 min. The measurements were always taken at the same time of the day. This method of measurement gave a relatively good repeatability of results.

The experiments were carried out at two light intensities, 3000 and 10 000 lux, in order to elicit wider differences in the influence of ammonium and nitrate salts (Hofstra, Koch-Bosma, 1970).

RESULTS

Growth dynamics of the plants expressed in terms of dry weight were as follows: at light intensity of 3000 lux 60 ± 1 mg for the nitrate solution and 43 ± 4 mg for the ammonium solution; at light intensity of 10 000 lux 132 ± 11 mg for the nitrate solution and 62 ± 3 mg for the ammonium solution. This indicates that plant growth was more intensive on the nitrate solution than on the ammonium one. The difference was larger when light of higher intensity was applied. The bioelectric potential of the leaves of the plants (Fig. 1) indicates that there are wide differen-

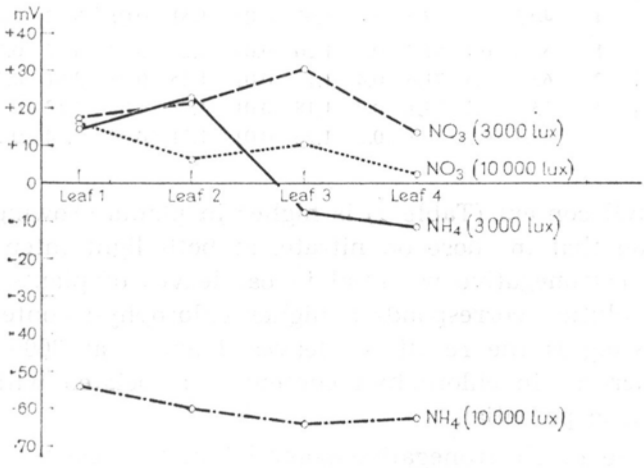

Fig. 1

ces in the electrophysiological characteristic of plants growing on nutrient solutions containing nitrogen in various forms. At an illumination of 3000 lux the first and second leaves have a similar potential, differences appear only in the 3rd and 4th leaves. In the case of ammonium solution the potential is negative and for the nitrate solution positive. Wider differences in the bioelectric potential occur at 10 000 lux. In this case the leaves of plants on nitrate solution exhibit a positive potential, whereas on ammonium solution their high potential is negative. The difference varies between 64 and 74 mV.

In view of the differences found in the bioelectric potential of plants growing on various forms of nitrogen, it was attempted to correlate it with the content of potassium (as the ion associated with the cell electric potential) (Sinyukhin, Vyskrebentseva, 1967). Potassium determinations in the leaves (Table 1) do not, however, show any strict correlation between the content of this element in the particular leaves and their electric potential, although total potassium content is higher in the case of ammonium salts, this finding its expression in the electronegative potential.

Table 1

Potassium, chlorophyll and phosphorus content in oat leaves growing under various light intensities (means from 5 replications)

Light intensity, lux	Leaf no.	Potassium content, mg/g dry weight		Chlorophyll content, mg/g fresh weight		Phosphorus content, mg/g dry weight	
		NO_3	NH_4	NO_3	NH_4	NO_3	NH_4
3000	1	43.2 ±0.3	64.3 ±0.3	1.10 ±0.07	1.34 ±0.02	4.09 ±0.41	5.64 ±0.12
	2	47.9±0.4	52.9 ±0.8	1.08 ±0.02	1.11 ±0.01	5.82 ±0.22	7.19 ±0.38
	3	42.3 ±0.2	52.4 ±0.3	0.88 ±0.01	1.71 ±0.01	6.49 ±0.03	6.67 ±0.23
	4	40.2–	57.4 ±0.4	1.07 ±0.01	1.51 ±0.01	8.72 ±0.03	9.75 ±0.13
10000	1	58.3 ±0.1	81.2 ±0.2	1.20 ±0.03	1.28 ±0.02	3.37 ±0.14	4.20 ±0.11
	2	62.4 ±0.5	71.6 ±0.4	1.18 ±0.01	1.25 ±0.03	3.91 ±0.20	4.29 ±0.10
	3	75.2 ±0.2	73.1 ±0.2	1.18 ±0.01	1.28 ±0.06	4.12 ±0.06	5.57 ±0.08
	4	69.3 ±0.3	56.1 ±0.2	1.26 ±0.01	1.31 ±0.02	7.84 ±0.23	8.21 ±0.14

Chlorophyll content (Table 1) is higher in plants growing on ammonium solution that in those on nitrate, at both light intensities. Thus, to a more electronegative potential in oat leaves of plants growing on ammonium solution corresponds a higher chlorophyll content. Particularly interesting is the result for leaves 3 and 4 at 3000 lux, where a sudden increase in chlorophyll content is associated with a leap in their bioelectric potential.

In the case of electronegative potential in the leaves, an increased phosphorus accumulation is observed, noticeable in plants growing on ammonium solution (Table 1) as compared with those on nitrate.

DISCUSSION

The electric potential of plants measured in the present study is the resultant of diffusion potential and membrane potential (Parkinson, 1966). When the same method of measurement is applied, it appears that the contribution of diffusion potential to the measured value is relatively stable, thus the observed differences in electric potential seem to be associated with the membrane potential. Elucidation of the mechanism of electric potential arising on the tissue or organ surface requires separate investigations, nevertheless the existence of links between this potential and metabolism seems doubtless (Thomas, 1939; Opritov, 1958).

The present experiments indicate that the differences in the response of plants to the form in which nitrogen is supplied find their reflection in the bioelectric potential of these plants. On ammonium solution the bioelectric potential of plants is more negative than on nitrate solution (Fig. 1). It is interesting that the electric polarity of the plants shows wider differences with changes in light intensity in the case of plants growing on ammonium and not nitrate solution (Fig. 1). These results seem to confirm the observations of other authors who report that external factors such as temperature or light have a more pronounced effect on plants growing on ammonium than on nitrate solution (Hofstra, Koch-Bosma, 1970; Zsods, 1972). The observed differences in the bioelectric characteristic are difficult to explain on the basis of analysis of potassium content since there is no unequivocal correlation between its content in the particular leaves, although practically on ammonium solution this content is higher and is accompanied by a high electronegative potential. The positive correlation between electric polarity and chlorophyll content is evidence of a relation between the activity of metabolic systems and the bioelectric potential. The rise in the chlorophyll level in leaves of plants growing on ammonium solution as compared to the level of those on nitrate is connected with the electronegative potential (Figure 1, Table 1), this, however, in view of the lack of measurements of gas exchange, cannot be referred to changes in the photosynthetic activity of these leaves. Zajączkowska (1973) demonstrated an enhanced photosynthesis in plants growing on ammonium solutions.

The organic matter increment observed in the present experiment is higher on nitrate solution than on ammonium, this seemingly indicating a higher photosynthetic activity of the plants in the former case. The results obtained at present confirm those of a number of authors who called attention to the differences in the metabolism of plants growing on nutrient solutions with nitrogen in various forms (Stabrowska, 1958; Gumiński et al., 1957; Zajączkowska, 1973; Breteler, 1973). These differences are manifested in the electrophysiological characteristic, although further studies will be required to answer the question which link in metabolism is directly involved in the observed changes in bioelectric potential. The investigations on the influence of ammonium and nitrate salts revealed a correlation between the value of the leaf electric potential and their phosphorus content. The more negative the potential the higher the content of this element in the leaves, this confirming the results of Opritov (1958), Opritov and Zhuravskaya (1964).

Since the experiments have to be carried out over a long time span, in further investigations eventual changes in electric polarity during plant growth and development should be taken into account (Sinyukhin, Stolarek, 1961; Paszewski, Gowin, Zawadzki, 1973).

CONCLUSIONS

1. Differences were found in bioelectric potentials of plants growing on ammonium and nitrate nutrient solutions. On ammonium solution the potential is more negative than on the nitrate one, and the difference increases with higher light intensity.

2. No direct correlation was noted between the leaf bioelectric potential and potassium content in them, on the other hand, there is a positive correlation with chlorophyll content in the leaves, a higher chlorophyll content corresponding to a more negative potential.

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Wpływ soli amonowych i azotanowych na potencjał bioelektryczny liści owsa (Avena sativa L.)

Streszczenie

Przedmiotem pracy było przebadanie wpływu różnych form azotu na potencjał bioelektryczny liści owsa rosnącego w zróżnicowanych warunkach świetlnych. Wykonane pomiary wykazały różnice w potencjale bioelektrycznym liści roślin rosnących na pożywce amonowej bądź azotanowej. Na pożywce amonowej jest on bardziej elektroujemny i różnica ta jest większa przy wyższym natężeniu światła. Przeprowadzone analizy zawartości potasu i chlorofilu w liściach wykazały brak bezpośredniej korelacji między obserwowaną wielkością potencjału a zawartością potasu, natomiast dla chlorofilu wzrost jego zawartości wiązał się z elektoujemnym potencjałem badanych liści.