UNIVERSITY of GUELPH

Ontario Agricultural College
Department of Horticultural Science
Guelph, Ontario CANADA
N1G 2W1
Tel. (519) 824-4120
Fax. (519) 767-0755

MELiSSA

Memorandum of Understanding
ECT/FG/MMM/97.012

TECHNICAL NOTE: 40.2

Composition of Edible and Non-Edible Fractions of Crops in the MELiSSA Menu

Version: 1
Issue: 0

Cloutier G., Dixon M.A.

June 1998

DOCUMENT CHANGE LOG

VERSION	ISSUE	DATE	OBSERVATION
1	0	20/05/98	Original Draft
1	2	26/05/98	Final Version

TABLE OF CONTENTS

COMPOSITION OF EDIBLE AND NON-EDIBLE FRACTIONS OF CROPS IN THE MELISSA MENU

1.0 - INTRODUCTION

1.1 - Main Results of Previous MELiSSA-HPC Work

Current research initiatives in the MELiSSA project have included modelling activities in the development of stoichiometric equations based on the four main metabolic pathways (catabolism of glucose, anabolism of proteins, CO_2 assimilation and the synthesis of reserve carbohydrates) (Lasseur, 1998). Models have grown to include steady state simulations with higher plants (Poughon, 1997).

In the mass balanced (steady-state) simulation incorporating higher plants, the growth of plants in the HPC was represented by a series of stoichiometric equations similar to those established for the different compartments of the MELiSSA loop. The HPC was divided into two main components; edible and inedible (waste; roots, shoots, leaves). Edible components were further sub-divided into a digestible and a dietary fibre (non-digestible) component. In the global model, the C, H, O, N and S compositions, as well as the yields of fibre/edible, waste/edible and the water content of the edible and non-edible part of the plant at harvest were calculated and tabulated from various data sources (Soucy *et al*, 1990; Soltner, 1988). These compositions and yields generally represented those obtained from earth soil cultivation and assumed that biomass produced in controlled conditions was identical in composition.

Field grown crops experience stresses that are eliminated in controlled environments, such as sub-optimal and variable temperature, radiation, nutrient supply, humidity, water availability, and pests and disease. In controlled environments, the elimination of such stresses has implications on the mineral composition of edible and in-edible fractions, particularly if essential nutrients are applied through hydroponics. Under conditions of unlimited nutrient supply such as those afforded in hydroponics systems, higher plants typically exhibit luxuriant uptake of essential nutrients (particularly NH_4-N and NO_3-N) (Marschner, 1995; Aldrich, 1980; Wolf and Wasserman, 1972). These compositional changes are primarily a result of increased mineral supply but higher light intensities and CO_2 concentrations in closed environments are also expected to have the same effect on composition.. Higher growth rates in closed environments are associated with the integrated effects of higher light intensities, CO_2 concentrations and an unlimited nutrient supply.

A knowledge of realized biomass composition in controlled environments will do much to improve the accuracy of life-support system sizing estimates, recycling efficiencies and the nature of dietary plans. Since the nutritional composition of MELiSSA candidate crops grown in controlled environments is expected to differ significantly from their field grown counterparts, this technical note is aimed at improving estimates of mineral composition of the edible and inedible fractions of the MELiSSA menu.

1.2 - Evaluation of Existing Literature

A review of the existing controlled environment agriculture literature yielded very few estimates of crop mineral composition. In fact, at present, only two primary sources were used to compile proximate and mineral composition of edible and in-edible fractions in this study.

The most comprehensive of these sources is an M.Sc. thesis by John McKeehen of Purdue University (McKeehen, 1994). McKeehen examined the proximate and mineral composition of five U.S. CELSS candidate crops, four of which are represented in the current MELiSSA menu (rice, wheat, potato and lettuce - the fifth being radish which is not currently on the MELiSSA candidate list). McKeehen's work represents the only complete comparison of the composition of field and chamber grown crops. In fact, this work is in itself a compilation of estimates obtained in Purdue University's growth chamber (rice), Utah State University's growth chambers (wheat) and the Kennedy Space Centre's Biomass Production Chamber (wheat, potato and lettuce). Field estimates were obtained at the Purdue University O'Neill Research Centre. Information derived from McKeehen's thesis forms the bulk of this technical note.

The second source, Wheeler *et al* (1996), provides information on soybean proximate composition. While additional data is presented on wheat and potato composition, they are very similar if not identical to those cited by McKeehen (1994).

No information could be found on the composition of spinach, onion or tomato composition grown in controlled environment chambers.

No reliable estimates of water content could be found in the literature. Water content is a difficult parameter to measure since resulting data are largely influenced by sampling methods. At this time it is not possible to provide reliable estimates of water content for any MELiSSA candidate crop grown in chamber conditions.

1.3 - Culture Conditions

The chamber environment conditions under which candidate crops were grown and from which subsequent composition estimates were obtained are summarized in Table 1 (McKeehen 1994, Wheeler *et al*, 1996).

	Rice (cv. 'Ai-Nan-Tsao')	**Potato** (cv. 'Norland')	**Lettuce** (cv. 'Waldmann's Green')	**Wheat** (cv. 'Yecora Rojo')	**Soybean** (cv. 'McCall')
Culture	NFT[1] ½ x Hoaglands[2] (NO_3^- only)	NFT ½ x Hoaglands (NO_3^- only)	NFT ½ x Hoaglands (NO_3^- only)	NFT ½ x Hoaglands (NO_3^- only)	NFT ½ x Hoaglands (NO_3^- only)
Harvest (days)	85	105	25	85	85
Photoperiod	10 hrs	12 hrs	18 hrs	20 hrs	12 hrs
Lamp Type	HPS	HPS	fluorescent	HPS	HPS
PPF($\mu mol m^{-2} s^{-1}$)	665	850	325	750	700
Temperature (°C)	32 °C light 26 °C dark	20 °C light/16 °C dark until day 40 then constant 16 °C	23 °C continuous	24 °C light/20 °C dark until day 16 then 20 °C light/16 °C dark	26 °C light/20 °C dark
R.H. (%)	72 ± 5%	75%	65%	75%	
CO_2 (ppm)	1500	1200	varied	1200	

Table 1. Culture conditions for chamber estimates of crop composition for MELiSSA candidate species. Adapted from McKeehen (1994).

[1] NFT refers to the Nutrient Film Technique, a hydroponics culture system in which plants are grown in pitched troughs with a continuous flow of nutrient solution through the root zone (refer to TN 40.1 for a more complete description).

[2] ½ Strength Hoagland's means that all salts in the solution are ½ x the concentration of the standard full strength Hoagland's solution. A standard Hoagland's solution does not contain NH_4^+-N.

2.0 - Proximate Composition of Some MELiSSA Candidate Crops

For each of the MELiSSA candidate crops, the proximate composition estimated at harvest, as reported by McKeehen (1994) and Wheeler *et al* (1996), is presented.

2.1 - Rice Proximate Composition

Plant Part	**Source**	**Protein (% dwb)**	**Fat (% dwb)**	**Ash (% dwb)**	**Carbohydrate (% dwb)**	**Fibre (% dwb)**	**Caloric Content (K cal g^{-1})**
Grain	Chamber[1]	17.0	3.1	1.9	78.0	----	3.9
	Field[1]	10.7	2.4	1.7	85.2	----	3.7
	MELiSSA[2]	8.4	2.6	----	85.7	3.4	----
Vegetative	Chamber[1]	21.2	1.7	16.1	61.0	----	----
	Field[1]	4.5	1.7	20.6	73.2	----	----
Roots	Chamber[1]	20.8	1.4	19.9	57.9	----	----
	Field[1]	2.6	2.9	41.0	53.5	----	----

[1] Data obtained from McKeehen (1994),[2] Data obtained from Poughon (1997)

Table 2. Rice Proximate Composition

2.2 - Wheat Proximate Composition

Plant Part	**Source**	**Protein (% dwb)**	**Fat (% dwb)**	**Ash (% dwb)**	**Carbohydrate (% dwb)**	**Fibre (% dwb)**	**Caloric Content (K cal g^{-1})**
Grain	Chamber[1]	19.1	3.1	2	73.2	2.7	4.0
	Field[2]	16.3	2.3	1.9	79.5	----	4.2
	MELiSSA[3]	13.8	2.4	----	71.7	12.1	----
Vegetative (Chaff and Straw)	Chamber[2]	5.6	1.2	8.3	84.9	----	----
	Field[2]	4.3	1.1	12.5	82.2	----	----
Roots	Chamber[2]	14.9	0.4	10.9	73.8	----	----

[1] Data obtained from Wheeler *et al* (1996), [2] Data obtained from McKeehen (1994),[3] Data obtained from Poughon (1997)

Table 3. Wheat Proximate Composition

2.3 - Potato Proximate Composition

Plant Part	Source	Protein (% dwb)	Fat (% dwb)	Ash (% dwb)	Carbohydrate (% dwb)	Fibre (% dwb)	Caloric Content (K cal g^{-1})
Tuber	Chamber[1]	15.2	0.7	7.6	74.2	2.3	3.7
	Field[2]	10.4	0.5	6.1	84.6	----	3.9
	MELiSSA[3]	10.2	0.6	----	76.8	12.5	----
Vegetative	Chamber[1]	11.9	2.9	23.4	61.8	----	----
	Field[2]	12.8	3.4	29.5	54.3	----	----
Roots	Chamber[1]	12.7	2.2	15.7	70.45	----	----
	Field[2]	6.7	4.1	32	57.2	----	----

[1] Data obtained from Wheeler *et al* (1996),[2] Data obtained from McKeehen (1994),[3] Data obtained from Poughon (1997)

Table 4. Potato Proximate Composition

2.4 - Lettuce Proximate Composition

Plant Part	Source	Protein (% dwb)	Fat (% dwb)	Ash (% dwb)	Carbohydrate (% dwb)	Fibre (% dwb)	Caloric Content (K cal g^{-1})
Leaves	Chamber[1]	27.4	4.6	21.8	35.8	10.3	2.9
	Field[2]	17.7	4.2	15.6	62.5	----	3.9
	MELiSSA[3]	30.6	5.4	----	26.9	37.2	----

[1] Data obtained from Wheeler *et al* (1996),[2] Data obtained from McKeehen (1994),[3] Data obtained from Poughon (1997)

Table 5. Lettuce Proximate Composition

2.5 - Soybean Proximate Composition

Plant Part	Source	Protein (% dwb)	Fat (% dwb)	Ash (% dwb)	Carbohydrate (% dwb)	Fibre (% dwb)	Caloric Content (K cal g^{-1})
Seed	Chamber[1]	36.3	19.9	7.4	25.4	11.1	4.26
	MELiSSA[2]	46.1	24.7	----	8.3	20.8	----

[1] Data obtained from Wheeler *et al* (1996),[2] Data obtained from Poughon (1997)

Table 6. Soybean Proximate Composition

3.0 - MINERAL COMPOSITION OF SOME MELISSA CANDIDATE CROPS

3.1 - Mineral Composition of Edible Fractions of MELiSSA Crops

		Mineral Composition of Edible Fractions (ppm)[1]										
Plant Part	**Field Vs. GC**	**Na**	**K**	**P**	**Mg**	**Ca**	**Ca/P Ratio[2]**	**Zn**	**B**	**Mn**	**Fe**	**Cu**
Rice Grain	Field	102	2432	2511	--	364	0.03	--	--	--	18	--
	GC	0	3067	3408	1366	103	0.03	39	0	19	4	6
Wheat Grain	Field	34	4205	4227	--	466	0.16	--	--	--	38	--
	GC	19	4267	3451	562	562	0.18	50	0	34	37	5
Potato Tuber	Field	500	67833	8833	1167	1167	0.14	--	--	--	100	--
	GC	28	26872	3267	470	470	0.04	27	4	14	104	7
Lettuce Leaves	Field	446	13069	1238	3366	3366	2.07	--	--	--	69	--
	GC	80	31161	3074	6349	6349	1.05	50	20	200	1437	13

[1] Data obtained from McKeehen (1994) and determined using Inductively Coupled Plasma (ICP) analysis

[2] Reports indicate that a human diet should maintain a Ca/P ratio of 1 for proper Ca absorption and retention (Stare and McWilliams, 1984). Fortification of calcium may be necessary.

Table 7. Mineral Composition of Edible Fractions of MELiSSA Crops

3.2 - Mineral Composition of In-Edible Fractions of MELiSSA Crops

		Mineral Composition of In-Edible Fractions (ppm)[1]									
Plant	**Plant Part**	**Na**	**K**	**P**	**Mg**	**Ca**	**Zn**	**B**	**Mn**	**Fe**	**Cu**
Rice	Veg.	234 (90)	44738 (23072)	4680 (945)	4830 (2152)	7995 (3996)	26 (101)	30 (2)	97 (562)	174 (437)	20 (30)
	Root	349 (339)	18463 (7791)	5176 (434)	1040 (2010)	3566 (2962)	30 (127)	2 (1)	19 (447)	7843 (4860)	60 (45)
Wheat	Chaff	24 (2)	19306 (1551)	4257 (292)	3372 (329)	3230 (890)	13 (5)	13 (5)	102 (7)	108 (79)	5 (2)
	Straw	99 (123)	66897 (27314)	3530 (680)	3091 (872)	5210 (3134)	8 (21)	93 (0)	58 (17)	162 (198)	5 (4)
	Root	118	45611	2428	1176	1846	15	48	35	840	56
Potato	Veg.	6 (105)	79174 (38450)	3118 (1774)	5746 (3505)	12969 (10819)	14 (114)	66 (22)	133 (217)	351 (2353)	7 (23)
	Root	133 (348)	48219 (31741)	2989 (1283)	7115 (2936)	5446 (7511)	29 (129)	28 (12)	1069 (265)	983 (4056)	206 (25)

[1] Data obtained from McKeehen (1994) and determined using Inductively Coupled Plasma (ICP) analysis. Bracketed values represent field estimates obtained by McKeehen (1994).

Table 8. Mineral Composition of In-Edible Fractions of MELiSSA Crops

4.0 - NITROGEN ALLOCATION AND PHYTIC ACID CONTENT OF SOME MELISSA CANDIDATE CROPS

4.1 - Nitrate Accumulation

In hydroponics nutrient solutions, nitrogen is often added at an excess concentration so as not to be limiting. The initial response of a crop to added nitrogen is to increase the yield per unit area, and to a lesser extent, to increase protein content (Aldrich, 1980). Aldrich also notes that there is an increase in nonprotein nitrogen (NPN) (ibid). NPN is defined as peptides too small to be precipitated and filtered, free amino acids, amides and other nonpolymeric nitrogen constituents of higher plants. Traditional protein determination methods assume the absence of significant quantities of NPN. Leafy vegetables tend to accumulate NPN in the form of nitrate (Corre and Breimer, 1979). Nitrates ingested through leafy vegetables can then be converted to nitrites by the oral micro-flora in humans and can then be absorbed by the blood to form methemoglobin, which is unable to transport oxygen. Methemoglobin can result in asphyxia which is more pronounced in young children. Nitrate is also capable of combining with amines to form carcinogenic nitrosamines.

Lettuce generally contains very high levels of nitrates (Wolf and Wasserman, 1972). Increasing the nitrogen supply has been shown to raise the nitrate content of leafy vegetables but to produce small effects if the edible portion is a root, fruit or seed (Aldrich, 1980). The concentration of NPN and nitrates in leafy vegetables, then, is of concern when crops are grown under non-limiting nitrogen conditions, or if nitrate is the prime nitrogen source in solution. It is suggested that these effects can be mitigated if nitrogen is supplied as ammonium, since much of the nitrogen accumulated by higher plants needs to be reduced anyway before it is incorporated into amino acids. The NPN and protein bound nitrogen levels for MELiSSA candidate crops are included for reference.

4.2 - Phytic Acid Concentrations

Cereals and legumes contain significant amounts of phosphorus in the form of phytic acid (myo-inositol hexaphosphate) (Reddy *et al*, 1989). Phytic acid can serve as a phosphorus reservoir in seeds and grains during ripening and reaches highest concentrations at seed maturity. Phytic acid is of concern since it has the ability to complex certain dietary minerals (eg. Ca^{2+}, Zn) thereby reducing their bio-availability. Further environmental factors in the field have been shown to increase phytic acid levels in soybean (Raboy and Dickinson, 1993). In general there is a linear relationship between phosphorus availability and seed phytic acid content in soybean (ibid). A critical phosphorus concentration in hydroponics solution, above which the negative dietary effects of phytic acid are observed, could not be determined from the literature. Nonetheless, a summary of phytic acid levels in MELiSSA candidate crops is included for reference.

		Phytic Acid Content and Nitrogen Allocation in MELiSSA Candidate Crops				
Plant	**Plant Part**	**% Protein from Total N[1]**	**% Protein from Non-Protein Nitrogen[1]**	**% Protein from Nitrate Nitrogen[1]**	**% Phytic Acid**	**Total P (ppm)**
Rice	Grain	17.0 (10.7)[2]	0.4 (1.2)	0.0 (0.0)	2.0 (1.5)	4198 (3433)
	Veg.	21.2 (4.5)	10.7 (0.7)	4.5 (0.0)	----	----
	Root	20.8 (2.6)	6.7 (0.1)	1.9 (0.0)	----	----
Wheat	Grain	22.3 (23.2)	3.4 (6.5)	0.0 (0.0)	1.3 (1.7)	4808 (3451)
	Chaff	13.2 (8.9)	5.2 (3.7)	0.6 (0.0)	----	----
	Straw	23.2 (5.5)	17.7 (2.1)	13.0 (0.1)	----	----
	Root	33.3	18.4	8.5	----	----
Potato	Tuber	20.0 (12.)	13.2 (5.5)	0.1 (0.1)	----	----
	Veg.	25.0 (17.2)	13.7 (4.4)	7.9 (1.9)	----	----
	Root	26.5 (9.2)	13.5 (2.5)	9.5 (2.0)	----	----
Lettuce	Leaves	33.4 (23.5)	18.1 (4.5)	14.2 (1.6)	----	----
	Root	26.6 (15.7)	16.3 (9.1)	6.2 (3.0)	----	----

[1] Total % nitrogen is used to calculate % protein by applying a factor of 6.25 Total Non-protein nitrogen (NPN) and nitrate nitrogen are both expressed as a percentage of the total protein content.

[2] Bracketed values represent estimates of field grown crops. All data is presented as obtained by McKeehen (1994).

Table 9. Phytic Acid Content and Nitrogen Allocation in MELiSSA Crops.

5.0 - SUMMARY

The results presented above indicate that;

i) Crops produced under controlled conditions exhibited higher protein contents in all plant parts than their field grown counterparts (wheat, rice, potato and lettuce) although the degree of statistical significance is variable (not significant for potato tubers and wheat chaff). Comparisons could not be made between chamber and field grown soybean. These increases are attributable to the luxuriant uptake of nitrogen in hydroponics solutions,

ii) Concentrations of fat, ash and carbohydrates were more variable and the response depended on the particular crop in question. No set of 'rules' can be established at this stage to predict individual crop composition response to controlled conditions or un-limited nutrient supply. However it is important to note that higher ash contents observed in field grown crops may be the result of soil contamination,

iii) The mineral composition of chamber grown and field crops was more variable. The response depended on the crop and the mineral in question. Generally an increase in mineral composition can be attributed to the luxuriant uptake of ions in solution.

iv) Total nitrogen content increased for all plant parts of all crops grown in controlled conditions as compared to the field. This increase is believed to be the result of luxuriant uptake of nitrogen in solution,

v) Non-protein nitrogen, particularly nitrate, was found to increase in a number of inedible plant parts grown under controlled environments. Again, this response is attributed to luxuriant uptake of nitrogen,

vi) Differences were observed in phytic acid content of wheat and rice grown in chamber conditions relative to their field counterparts. This is consistent with higher P application and luxuriant uptake in hydroponics systems.

These results can be incorporated into future MELiSSA-HPC simulations and replace estimates of composition obtained from field literature. Crops for which controlled environment composition was not available (spinach, onion and tomato) will require further experimentation.

6.0 - REFERENCES

Aldrich, S.R., 1980. Nitrogen in relation to food and energy. Agricultural Experiment Station, University of Illinois, pp. 97-110.

Corre, W.J., and T. Breimer, 1979. Nitrate and nitrite in vegetables. PUDOC, Wageningen.

Lasseur, Ch., 1998. MELiSSA Final Report. ESA.ESTEC MCL/2574.CHL

Marschner, 1995. Mineral Nutrition of Higher Plants. Academic Press, Toronto.

McKeehen, J. 1994. Nutrient Content of Select Controlled Ecological Life Support System Candidate Species Grown Under Field and Controlled Environment Conditions. M.Sc. Thesis, Purdue University.

Poughon, L., 1997. Including a Higher Plant Chamber in the MELiSSA loop: Description of an HPC for MELiSSA loop steady state simulations. MELiSSA Technical Note 32.3, Contract ECT/FG/CB/95.205.

Raboy, V. and D.B. Dickinson, 1993. Phytic acid levels in seeds of Glycine max and G. soja as influenced by phosphorus status. Crop Sci. 33:1300-1305.

Reddy, N.R., Pierson, M.D., Sathe, S.K., and D.K. Salunkhe, 1989. Phytates in Cereals and Legumes. CRC Press, Inc., Boca Raton, FL.

Soltner D., 1988. Phytotechnie, les grandes productions vegetales, Tome 2. Sciences et Techniques Agricoles.

Soucy S.W., Fachmann, W., and Kraut H., 1990. Food composition and nutrition tables 1989/1990. Wissenshaftlische Verlagsgesellschaft mbH Stuttgart.

Stare, F.J. and M. McWilliams, 1984. Living Nutrition. John Wiley and Sons, New York.

Wheeler, R.M., Mackowiak, C.L., Sager, J.C., Knott, W.M. and W.L. Berry, 1996. Proximate Composition of CELSS Crops Grown in NASA's Biomass Production Chamber, Adv. Space Res. 18:4/5 pp 43-47.

Wolf, I.A. and A.E. Wasserman, 1972. Nitrates, nitrites and nitrosamines, Science 177:15-19.