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Innovative Techniques to Reduce Chilling Injuries in Mango (*Mangifera Indica* L.) Trees under Mediterranean Climate

Vittorio Farina[a], Luigi Tripodo[a], Giuseppe Gianguzzi*[a], Giuseppe Sortino[a], Diego Giuffre[a], Ugo Lo Cicero[b], Roberto Candia[b], Alfonso Collura[b].

[a]Department of Agricultural and Forest Sciences, Università degli Studi di Palermo, Italy
[b]Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Palermo, Italy
giuseppe.gianguzzi@unipa.it

As a tropical tree, mango (*Mangifera indica* L.) cultivated in Mediterranean climate needs protection against low temperatures. The aim of this work is to study the effect of traditional individual protective canopy protection systems in comparison with innovative typologies designed for this experiment on the physiological response of young mango trees during the cold season. We selected 25 four-year-old mango trees cv ‘Glenn’. Trees were divided into five different groups: not covered trees (NC); trees with windbreak protection using a shading net (SN); trees with windbreak protection using non-woven sheets (WB); fully covered trees using non-woven sheets (FC); fully covered trees with non-woven sheets and the addition of a 'heat exchanger' device (FC+). Their canopies were fully covered (FC**)** and (FC+) or enclosed by a hand-made individual windbreaks (SN and WB). We studied the evolution of temperature inside the canopy and evaluated the threshold of damage on leaves and shoots. We also monitored soil temperature under the trees. Precision self-made data loggers were assembled. A "heat exchanger" was realized for this experiment to try to recover heat from the ground and place it under the canopy of the plants. It was made with a 50 cm U-shaped aluminum pipeline using recycled materials; this was placed horizontally, 50 cm deep in the soil with one of two extremities above the soil and the other within the canopy. NC trees were damaged by cold temperature. More particular, the young shoot was injured by necrosis followed by fungal disease. The same behavior was observed in SN and WB when the canopy was only enclosed by the protection whereas FC tree shoots were intact. Non-woven sheets preserved intact the shoots only in the FC trees, as the canopies were completely covered by a closed space because the leaves and shoots were isolated from the outside. The ‘heat exchanger’ device increased, however minimally, the temperature in the closed space containing the canopy. The use of non-woven sheets, covering completely the canopy, allowed to preserve the shoots for future tree development.

1. Introduction

The mango (*Mangifera indica* L.) is the most important species of the Anacardiaceae family both for its world production and its wide global distribution. In Sicily, this crop is increasingly expanding in conjunction with the economical crisis of the citrus cultivation particularly along the Tyrrhenian coastal areas (Liguori et al., 2017). The climatic conditions prevailing in this area of Sicily, particularly during the cold seasons, differ greatly from those of most mango-growing regions. In fact the presumable average temperatures hover around 17 – 18°C, while the average rainfalls are close to 690**.**8 mm with 77 rainy days (Duro et al., 1996; Drago, 2005; Gianguzzi et al., 2015). Under the bioclimatic aspect, the station is referred to the upper thermos-Mediterranean lower subhumid bioclimatic belt (Gianguzzi et al., 2015). Hence, the possibility to cultivate mango in this areas is mainly subjected to the effect of temperature. The tree is not able to be cultivated in areas where the average of the coldest month is less than 15°C (Ochse et al., 1972) while the optimum growth temperature is between 24 and 26°C reaching 30 and 33°C for the stages of flowering and fruit development (Purseglove, 1968; Chachko, 1986). Temperatures between 15 and 33°C were found to be excellent for the pollen development (Issarakraisila and Considine, 1994) as well diurnal temperatures of 19°C and 13°C during the night are favourable for a good flower differentiation (Chen et al., 1999), whereas night

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temperatures below 10°C reduced by 50% the viability of the pollen. Fitchett et al. (2014) have shown that temperature is also a decisive factor to increase yield too. Generally the main factors of low temperature resistance are tree size (Carmichael; 1958), vigour (Singh and Singh, 1995) and canopy distance from the ground (Oppenheimer, 1952). Even if some varieties are resistant to -5.6 °C (Hayes, 1945; Jawada, 1962) Campbell et al. (1977) claim that gems damage occur also at 0°C. Hence, the possibility to protect young plants from temperatures below -3.3°C covering them with agave fiber and wood chips (Sturrock, 1951). Over the years, farmers have operated with more or less functional protective intervention, but do not exist, in the literature, studies designed to evaluate their effectiveness. For this purpose, it lends the non-woven fabric, a synthetic material used in agriculture which can be placed directly over the canopy to protect the tree from cold winds. The main advantages of direct coverage are the easy use and the cheap cost for installation (Gregoire, 1990). Primary utilized is in horticulture (Dantas et al., 2013) to protect plants from cold temperature (Jabłońska e Wadas, 2005) increasing the quality (Shijun et al., 2002). As regards the protection of individual fruit by coverage, Junya et al. in 2004 showed that the coverage with white non-woven fabric has given the best results on the mango. Nowadays, very few studies analyzed the possibility of protecting woody plants using the non-woven fabric in the early years of development (Jackson et al., 1986), covered the whole plant, reaching considerable results. Hamouz et al. (2006) report that the air temperature under the protective layer is increased by 2°C. Gimenez et al., (2002) have noted that undercover the temperature was always higher from 1 to 6°C compare to the open. In addition, another strategy would be to use the accumulated heat from the ground. The soil, is generally characterized by high thermal capacity (Hillel, 1998) and, generally, it should be possible to use the soil thermal reserve of more than 40 cm in depth as a source of heat at a temperature that for all purposes of our work we can consider constant. To be able to assess accurately the effects on the plant by the various treatments we used the BBCH scale. The BBCH scale (Biologische Bundesantalt, Bundessortenamt und Chemische Industrie) is a useful way to standardize the classification of the phenological stages of all species of mono- and dicotyledonous plants. Proposed by Bleiholder et al. (1989) and later in the extended version by Hack et al. (1992), it is based on the "cereal code" (Zadoks et al. 1974). The advantage is in the simplicity and ease of use for annuals, biennials and perennials; also describes both phases: vegetative and reproductive. A considerable effort has been made to study the usefulness of BBCH scale on mango phenology (Hernández *et al*., 2010). The objective of this work is to make a contribution on the physiological response of *Mangifera indica* L. plants, in relation to different protection systems (simple and combined) in Mediterranean area climate. We want to study the effect of such systems on the maintenance of the temperature inside the canopy, monitoring the performance of this parameter during the cold months and verifying, then, the phenological evolution and the plant capability to the vegetative growth. Also we want to evaluate the threshold of damage caused by low temperatures on plant foliage.

2. Materials and methods

2.1 Experimental site

The trial was carried out in an orchard located at Agostino Collura Farm in Acquedolci, province of Messina (Sicily, Italy; 38°3' N, 14°33' E; 50 m a.s.l.).

2.2 Plant Material

We selected 25 uniform 4-years-old mango trees grafted on Gomera 3 rootstock, spacing 4x2 m and trained to a globe shape. Trees were submitted to routinary cultural cares. Perimetric and diagonal windbreaks are on site to reduce harmful wind effects.

2.3 Experimental design

Trees were divided into five different groups: not covered trees (NC); trees with windbreak protection using a shading net (SN); trees with windbreak protection using non-woven sheets (WB); fully covered trees using non-woven sheets (FC); fully covered trees with non-woven sheets and the addition of a 'heat exchanger' device (FC+). Their canopies were fully covered (FC and (FC+) or enclosed by a hand-made individual windbreaks (SN and WB) and constituted by three poles and a metal mesh of large mesh support (20x20) covered by different materials (Figure 1).

2.4 The non-woven fabrics

The spun-bonded type (generic name of non-woven fabrics (NWF) obtained directly from polymers and not from a bottom of fibers or from pre-existing wires, is constituted by a mat of continuous threads extruded from a battery of spinnerets, with the intersection points between the wires same softened and bonded using heated presses.

2.5 The "heat exchanger" device

The "heat exchanger" device (HEX) consists of a cylindrical cable placed horizontally at 50 cm depth in the soil and by two conduits with thin aluminium cans (diameter: 64 mm) connected to the ends of the exchanger, one outcropping on the surface with the mouth a few cm above the ground, the other one with the outlet to some cm height from the ground level and placed inside the canopy created by the TNT protection. The conduits were made with a normal 70 mm in cable duct coiled tubing.

Figure 1. Different kind of canopy protection (on the first line, from left to right) and the relative effect of cold season on the canopy (on the second line): trees with windbreak protection using a shading net (SN); trees with windbreak protection using non-woven sheets (WB); fully covered trees with non-woven sheets and the addition of a 'heat exchanger' device (FC+). On the second line the effect of cold temperature after protection removal.

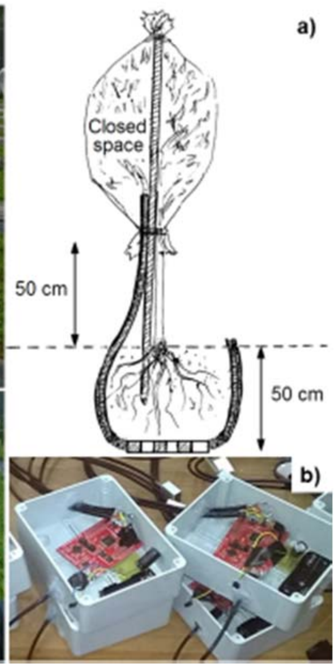

Figure 2. a) Heat exchanger dispositive; b) Self-built dataloggers based on a TI (Texas Instruments) MSP-430 microcontroller and equipped with TI TMP112 temperature sensors.

2.6 Data logging: devices and software

To create the monitoring network self-built data loggers have been assembled (Figure 2), each one equipped with three temperature sensors (Texas Instruments TMP112). The technical characteristics of the sensors are: maximum operating temperature +125 °C; minimum operating temperature -40 °C; accuracy with calibration down to ±0.17 °C; accuracy without calibration ±0.5 °C between 0 °C and 65 °C, ±1 °C between -40 °C and 125 °C; resolution 12 bit (corresponding to 0.0625 °C); supply voltage range 1.4 V to 3.6 V; digital output on I^2C bus. The datalogger consists of a sealed plastic box containing a Texas Instruments MSP-EXP430F5529LP module, based on a MSP-430 microcontroller, and a custom Printed Circuit Board (PCB) mounting a battery holder and power electronics that enables the device to be powered either by two AA batteries or via an USB cable. Each temperature sensor is connected to the module by a 4-conductors shielded cable, and is mounted on a small PCB encapsulated in a protective, high thermal conductivity epoxy cube. The microcontroller firmware was designed specifically to maximize the battery life and optimize the memory storage usage. The temperature is recorded every 15 minutes under 4 °C; over 4 °C the temperature is measured every 15 minutes, but the values are stored only if there is a difference of more than 0.5 °C respect to the last stored value. It was designed to connect via USB to a PC and to use a serial terminal (we choose the free software "Realterm", realterm.software.informer.com) for monitoring the unit status and to download the stored data (including battery status, number of data records, the three temperature sensors measurements, date and time of activation). Data logger were used (Figure 2) for the monitoring of the outside temperature, soil temperature (10, 30 and 50 cm in the soil) and inside the canopy of plants. Inside the rooms were positioned at the same height from the floor (50 cm) and with opposite north-south orientation (two sensors under each plant). External sensors were positioned at the same height from the ground always inside the uncovered plant canopy, always with north-south orientation. Moreover, it was measured the damage threshold by evaluating the percentage of shoots affected by cold damage of the first vegetative flow.

3. Results and discussions

The time course of soil temperature (Figure 3) showed a similar trend along the three depth but the temperature decreased from 50 to 10 cm of depth. The lowest temperature was observed at 10 cm during the night of 31th December and 1[th] January (3.3° C), at 30 cm during the night of 1[th] January (6.5°C) and at 50 cm during the night of 1[th] January (9.6°C). Figure 4 compares FC, FC+ and NC treatments. FC+ always showed the highest temperatures. Especially with the thesis FC, differences appear rather small while with NC trees when are more pronounced. Even during the coldest night of the trial, a positive role of the heat exchanger was confirmed: in fact in FC+ was detected an average temperature of 1.7° C while in the FC of 1.6° C and in the plants NC of 1.3° C.

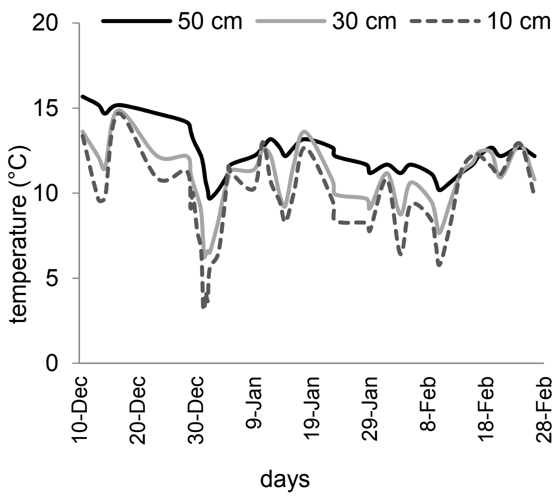

Figure 3. Time course of temperature (C°) measured at three different soil depth.

Table 1: Phenological stages in FC and FC+ trees. In NC, SN and WB the first vegetative flush was loss by cold temperature. I, II, III VF (First, second, third vegetative flush); RF (Reproductive Flush).

Date	I VF	RF	II VF	III VF
11/24//14	17			
12/09/14	110	510		
12/25/14	315	514		
01/05//15	315	514		
01/15/15	317	514		
02/09/15	317	515	27	
02/25/15	317	515	120	20
03/15/15	317	515	120	21
04/07/15	319	517	125	110
04/24/15	319	517	129	121
05/11/15	319	611	322	125
05/22/15	319	619	325	129
06/07/15	319	619	325	322
06/27/15	319	703		325

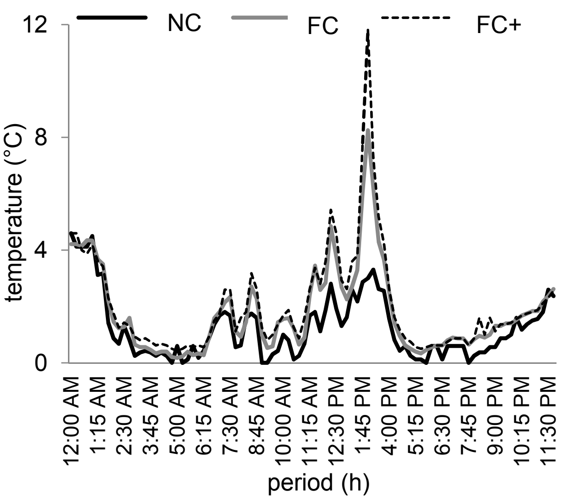

Figure 4. Time course of temperature (C°) in NC, FC and FC+ treatment during the coldest day (12/31/2014). Each value is the average of North and South sensors.

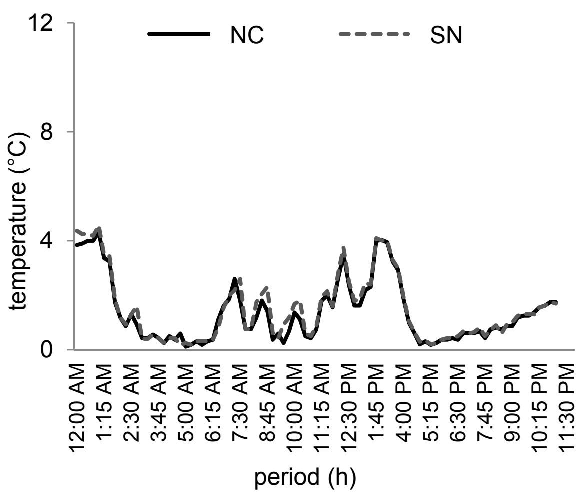

Figure 5. Time course of temperature (C°) in treatment NC and SN during the coldest day (12/31/2014). Each value is the average of North and South sensors.

The differences between the three treatments, that might seem irrelevant, combined with the protection of the canopy protected young shoots from the cold wind. Temperatures in SN and NC plants do not differ. During the coldest 24 hours (Figure 5) SN would seem to be a negative effect on the shoots and leaves (Figure 1). We have also verified that the first vegetative flush was burned by cold temperatures in both SN and NC treatments. Therefore, SN did not contribute to canopy protection in young trees. The negative aspects of the SN is the complete open of the top and the bottoms parts of the canopy. This fact clearly allows a better cold air circulation that, in very cold days, burn the young sprouts (Figure 1). Although the traditional protection with NWF (WB) in respect to traditional system (SN) than the protected plants with a windbreak net, maintained a best temperature inside the canopy, it does not permit to preserve the first vegetative flush. Hence, this system has not been helpful in preserve tree canopy. The damage threshold indicated an average percentage of 97% of shoots affected by cold damage in the NC, SN and WB and no injuries in FC and FC+ treatments. The BBCH scale is based on two vegetative flushes but, in our case are, are three (Table 1). In all treatments except FC and FC+, the first vegetative flush was burned by cold temperatures (Figure 1). The same behaviour was observed in the plants SN and WB when the 100% of the buds of first flush vegetation and reproduction were burned from the cold temperature with the development of necrosis followed by fungal disease.

4. Conclusions

As is well known, low temperature is the environmental factor that most affect the possibility of mango diffusion in Mediterranean climate. Therefore, in addition to collective wind deflector, the adoption of Individual plant protection from adverse temperature has always been a necessity for young mango trees. Hence, we analyzed the behavior of young mango plants during a winter in Mediterranean climate focusing our attention on traditional individual protective canopy protection systems in comparison with innovative typologies designed for this experiment.

The use of non-woven fabric, preserve the plants from cold temperature but just in FC and FC+ thesis, where the plants were completely covered, by creating a closed space where the canopy was isolated from the outside. In fact, traditional protection SN and WB, where the plants were only enclosed along the sides by shading net and non-woven sheets respectively showed a negative results with vegetative damages such as in NC treatment. More particular, in NC, WB and SN, the young shoot was injured by necrosis followed by fungal disease whereas in the FC and FC+ the shoots were intact.

Thus, a key role is being played by the closed space in which the leaves and shoots were isolated from the outside. In fact, the temperatures recorded inside the closed space were always higher (although a few °C degree) than the outside temperature. Therefore, we consider essential the action that the non-woven has have in stopping the action of cold air and wind preserving the leaves and the shoots during winter nights. In addition to the protection of the plant's canopy, the heat exchanger using in the FC+ treatment, permitted to use the accumulated heat from the ground.

Our study demonstrated the utility FC and FC+ treatments *vs* traditional protective solutions. Thus, the new solutions presented a greater simplicity of use, cheapness of the material and rapidity of installation. Now, we can affirm the total superiority of full coverage compared to all the other protective systems.

References

Bleiholder H., Van den Boom T., Langelüddecke P., Stauss R., 1989, Einheitliche Codierung der phänologischen Stadien bei Kultur-und Schadpflanzen. Gesunde Pflanzen, 41(11), 381.

Campbell C.W., Knight R.J., Zareski N.L., 1977, Freeze damage to tropical fruits in southern Florida in 1977. Proceedings of the Florida State Horticultural Society: 90: 254-257.

Carmichael W. W., 1958, Observations of cold damage to mangos in Dade county and the Lower West Coast. Proceedings of the Florida State Horticultural Society.

Chachko E.K., 1986, Physiology of vegetative and reproductive growth in mango (*Mangifera indica* L.) trees. Proceedings of the 1st Australian Mango Research Workshop, Quennsland. CSIRO. Melbourne.

Chen Y., Zhu J., Ye B., 1999, Effects of drought stress on active oxygen damage and membrane lipid peroxidation of leaves in mango (*Mangifera indica* L.).Sheng ming ke xue yan jiu,4(1).

Dantas M. S., Grangeiro L. C., De Medeiros J. F., Cruz C. A., Da Cunha A., 2013, Rendimento e qualidade de melancia cultivada sob proteção de agrotêxtil combinado com mulching plástico. Revista Brasileira de Engenharia Agrícola e Ambiental, 824-829.

Drago A., 2005, Atlante climatologico della Sicilia. Rivista Italiana di Agrometeorologia 2 67-83.

Duro A., Piccione V., Scalia C., Zampino S., 1996, Precipitazioni e temperature medie mensili in Sicilia relative al sessantennio 1926-1985. Atti 5° Workshop Progetto Strategico Clima, Ambiente e Territorio nel Mezzogiorno C.N.R., 1 17-109.

Fitchett J., Grab S. W., Thompson D. I., 2016, Temperature and tree age interact to increase mango yields in the Lowveld, South Africa. South African Geographical Journal, 98(1), 105-117, DOI: 10.1080/03736245.2014.924874.

Gianguzzi L., Papini F., Cusimano D., 2015, Phytosociological survey vegetation map of Sicily (Mediterranean region). Journal of Maps 1-7, DOI: 10.1080/17445647.2015.1094969.

Gimenez C., Otto R. F., Castilla N., 2002, Productivity of leaf and root vegetable crops under direct cover. Scientia Horticulturae, 94(1), 1-11, DOI: 10.1016/S0304-4238(01)00356-9.

Gregoire P., 1990, The nonwovens in specialised agriculture, Proceedings of the 11th international congress on the use of plastics in agriculture, New Delhi, India, 26 February-2nd March 1990.

Hack H., Gall H. T., Klemke R., Klose U., Meier R., Stauss A., Witzenberge R., 1993, The BBCH-scale for phenological growth stages of potato (*Solanum tuberosum* L.), Proceedings of the 12th Annual Congress of the European Association for Potato Research Paris, 153-154.

Hamouz K., Lachman J., Dvorak P., Trnková E., 2006, Influence of non-woven fleece on the yield formation of early potatoes. Plant Soil and Environment, 52(7), 289.

Hayes W. B. 1945, Fruit growing in India.

Hernández Delgado P.M., Agusti M., Aranguren M., Fernandez Galvan D., Galan Sauco V., Reig C., 2010. Phenological development stages of mango (*Mangifera indica* L.) according to the BBCH scale. 9th International Mango Symposium held during 8-12 April, Sanya, Hainan Island, China, 72. DOI: 10.1016/j.scienta.2011.07.027

Hillel D., 1998, Environmental soil physics: Fundamentals, applications, and environmental considerations. Academic press.

Issarakraisila M., Considine J. A., 1994, Effects of temperature on pollen viability in mango cv. 'Kensington'. Annals of Botany, 73(3), DOI: 10.17660/ActaHortic.1993.341.11

Jabłońska-Ceglarek R., Wadas W., 2005, Effect of nonwoven polypropylene covers on early tuber yield of potato crops*.* Plant, Soil and Environment 51.5: 226-231.

Jackson J. L., Ayers D., Parsons L. R., 1986, Performance of individual tree covers for cold protection of young citrus. Proc. Fla. State Hort. Soc. Vol. 99.

Jawada J. S., 1962. Frost damage in mango. Punjab Hort. Jour. 2:21-24 (cited from Hort. Abstr. 33:6219).

Junya L. D. F. C. W., Guangxiang Z. X. H. R. Z., Shaopeng L. 2004, Effect of Different Bagging Materials on Fruit Quality and Sticking Words in Red Mango (Tommy) [J].Chinese Journal of Tropical Crops, 1, 003.

Liguori G., Sortino G., Gentile C., Gianguzzi G., Saletta F., D’Asaro A., Inglese P., Farina V., 2017, Quality changes in fresh-cut mango cubes submitted to different concentration of active MAP. ISHS VIII International Postharvest Symposium: Enhancing Supply Chain and Consumer Benefits - Ethical and Technological Issues, Acta Horticulturae, In press.

Ochse J.J., Soule M.J., Dickman M.J., Wehlburg C., 1972, Cultivo y mejoramiento de plantas tropicales ysubtropicales (II tomo). Limusa-Wiley. México.

Oppenheimer Ch., Jafe, A., 1952. Frost damage to subtropical fruit trees during the winter 1948/49. Ministry of Agriculture Leaflet.

Purseglove J.W., 1968, Tropical crops dicotyledons (II tomo). John Wiley ans Sons. Inc. New York.

Shijun L., Lin L., 2002. Performance of Farm Nonwoven Fabric and Its Application to Vegetable Production in Spring and Winter. Technical Textiles 5: 007.

Singh, L. B., Singh R. N., 1995, Frost Injury to Tropical and Sub-Tropical Fruits at Saharanpur. Indian Journal of Horticulture 12.3: 108-114.

Sturrock D., 1951, Frost protection of young mango trees. Mango Studies, Florida Mango Forum.

Zadoks J. C., Chang T. T., Konzak C. F., 1974, A decimal code for the growth stages of cereals. Weed research, 14(6), 415-421, DOI: 10.1111/j.1365-3180.1974.tb01084.x.