NSW GOVERNMENT | Department of Primary Industries

FACTSHEET

Impacts and management of flooding and waterlogging in citrus orchards

Sandra Hardy

Industry Leader – Citrus, NSW DPI Ourimbah

Pat Barkley

Technical Advisor, Citrus Australia

Andrew Creek

District Horticulturist, NSW DPI Griffith

Nerida Donovan

Plant Pathologist, NSW DPI Camden

Photo by Bart Brighenti

The recent heavy rainfall and flooding events in NSW may cause some immediate damage to trees, but may also have significant long term impacts on citrus orchards, particularly those planted on heavy soils or those with impeded drainage.

Previous flooding events in the MIA

Previous flooding and high rainfall events occurred in the Murrumbidgee Irrigation Areas (MIA) in the 1930's and 40's (during the winter months) and the impacts of those events, combined with a tendency to over-water resulted in considerable decline in tree health and the death of many trees. Survey and research work undertaken by Dr. Lilian Fraser concluded that one of the main causes of tree death and decline was due to infection by the root rot fungus *Phytophthora citrophthora*.

At that time most citrus trees were grown on rough lemon or sweet orange rootstocks, both of which are highly susceptible to *Phytophthora* root and collar rots. Tree losses were aggravated by faulty irrigation practices, lack of adequate drainage and uneven soil types (Fraser 1942). Fraser along with horticulturists Benton, Bowman and Kebby in the NSW Department of Agriculture soon established that trees on trifoliata rootstock planted in infested soil in the MIA made very good growth.

Trifoliata is highly resistant to root rot caused by *Phytophthora*, while Troyer and Carrizo citranges although they have less resistance, are still vastly superior to rough lemon or sweet orange. However trifoliata and the citranges succumb to another problem: sudden death (known overseas as dry root rot). While some researchers overseas have suggested that the fungus *Fusarium* plays a role in dry root rot, it has been conclusively established by three years of research conducted on farms in the MIA (Shearman, 2006) that intermittent waterlogging is the underlying predisposing cause of sudden death in that region.

In the past 50 years there have been many changes with regards to citrus plantings in the MIA. New plantings have largely used rootstocks such as trifoliata and the citranges that are better able to cope with *Phytophthora* root rot. Irrigation systems and practices have changed and become more efficient and precise in delivering the right amount of water to match site conditions and tree needs. However soil type can be extremely variable, even within a block — making it difficult to achieve the ideal soil moisture content for all trees or blocks. Butler in his 1979 CSIRO survey of horticultural soils in the MIA noted that very few soils were free from becoming waterlogged, that some areas are difficult to clear of surplus surface water and sudden changes in soil type across paddocks are common. Many new horticultural plantings have probably been made on less than ideal soils for citrus. Even with previous site improvements such as subsurface tile and mole drains and the more recent use of laser levelling and the use of mounding in the tree row – it may not be enough to get through unscathed during the recent high rainfall and flooding events.

What is waterlogging?

Waterlogging occurs whenever water enters the soil at a faster rate than it can drain away. It can be caused by heavy or prolonged rainfall, over-irrigation, flooding or the presence of a permanent or temporary (perched) high water table. The duration and severity of the waterlogging event is influenced by the amount of water entering the system, the topography of the site, soil structure and the water absorbing capacity of the soil.

The soil is made up of different sized soil particles interspersed with different sized spaces or pores. The smaller pores (less than 0.5 mm wide) are usually filled with water while the larger pores are usually filled with air. Good horticultural soils normally have between 10 to 30% of their volume composed of larger pores that are filled with air and 10% is considered the minimum air content for healthy root growth depending on plant species. Waterlogging occurs when both the small and large air pores in the soil become filled with water, usually as a consequence of the water failing to drain away quickly enough from the large pores — resulting in a soil which has little or no oxygen, an environment referred to as anaerobic.

Topography plays an important role in the horizontal movement of water across the landscape, with water tending to collect in the lower, flatter areas — which will normally be subject to waterlogging for longer periods than higher ground.

The vertical movement of the water through the soil profile is largely controlled by soil type and structure. Generally the higher the clay content of the soil, the slower the water will move through it and the longer it will remain wet. Additionally any impermeable layers in the subsoil such as natural clay or rock layers or a compacted layer caused by ploughing or vehicular traffic will also further impede drainage – resulting in a perched water table which causes the soil above to remain saturated.

Waterlogging also has an impact on soil structure by dispersing the clay particles, which further reduces pore space. The subsoil will usually be subject to much longer periods of waterlogging and anaerobic conditions. Care must be taken not to take heavy machinery onto wet soils as this will cause further compaction and deterioration of soil structure.

What happens in waterlogged soils?

There are a number of biological and chemical processes that occur once the soil becomes waterlogged and devoid of oxygen — how important these changes are will depend on the length of time the soil remains saturated.

When soils become saturated, gas diffusion and exchange between the soil and the atmosphere is impeded because the air pores are filled with water. This results in changes in the concentration of gases such as oxygen (O_2) and carbon dioxide (CO_2). Any O_2 present will be quickly depleted by the plant roots and the microorganisms in the soil as they undertake their normal functions. CO_2 levels will increase as a result of respiration by the plant roots and microorganisms. The O_2 depletion rate is also affected by soil temperatures (faster at higher temperatures) and the amount of organic matter and microorganisms present in the soil.

When the plant roots do not receive an adequate supply of O_2 their growth is slowed or stopped. Root tips can start to die after 24–48 hours without oxygen. Waterlogging and reduced O_2 levels in the soil affect the roots ability to absorb water and nutrients and when this happens the root sends a signal to the tree which triggers the leaf stomata to close to reduce water loss. Because the roots cannot take up water the leaves begin to wilt. Most research concludes that low O_2 and not excess CO_2 is likely to be the major source of damage associated with short term soil flooding. The effects of waterlogging can be less severe if the water is flowing, because moving water carries dissolved oxygen and also carries away any toxins.

The loss of O_2 makes the soil anaerobic causing changes in biological and chemical processes. If soils remain waterlogged and these anaerobic conditions persist for more than a few days these changes in biological activity and chemical processes may become important. CO_2 and various anaerobic by-products such as sulfur, hydrogen sulfide, methane, and organic acids start to accumulate, some of which affect root growth and function. Of all the by-products produced, hydrogen sulfide appears to do the greatest damage to citrus roots. These changes can also lead to nutrient imbalances. Nitrogen is the first ion to undergo reduction resulting in losses of plant available nitrates. After nitrogen, the oxides of manganese and iron are converted into more soluble forms and in acid soils iron toxicity may be a problem. Soil pH has a big effect on what nutrients will become either more or less available in flooded soils.

Symptoms, effects and tolerance of citrus to waterlogging

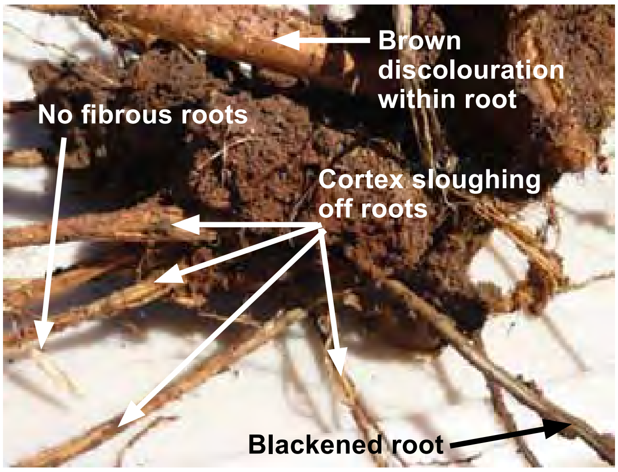
Tree symptoms vary with the frequency and duration of waterlogging and rootstock.

Root distribution in the soil is dependent on soil type, subsoil characteristics, rootstock characteristics and the irrigation regime (frequency and distribution in the root zone). The most active absorption of water and nutrients is carried out by the fibrous or feeder roots and these are typically in the top 15–30 cm of the soil. The healthiest roots are usually in this top layer which should be the first to drain.

Because waterlogged trees cannot take up water, one of the first symptoms seen is wilting of the foliage and shoots, particularly in warm weather.

If root damage is excessive or soils remain waterlogged for longer periods the tree can show more severe symptoms such as leaf drop, reduced growth, yellow veins, small yellowish leaves and dead twigs — symptoms which are also similar to those caused by *Phytophthora* root rot. The fibrous roots are sloughed off and even the larger roots die or are weakened. Dead areas develop in the larger roots which are initially brown and water soaked and become black as they are invaded by soil microorganisms. Because the above ground parts of the tree mirror what is underneath the soil, trees will respond to any major damage to the root system by reducing the size of their canopy either by dropping leaves or reducing the number and length of shoots.

Citrus rootstocks vary in their ability to tolerate waterlogging which is also partly governed by their susceptibility to or infection by *Phytophthora* root rot. Table 1 gives some general ratings for common citrus rootstocks. How trees will cope and respond to the effects of waterlogging also depends on soil type and pH, the amount of roots damaged and other rootstock characteristics such as the ability to generate new roots. For example vigorous rootstocks such as rough lemon can rapidly replace roots if soil conditions become more favourable.



Citrus roots showing various symptoms of waterlogging damage, including cortex sloughing, brown and black internal discoloration and a lack of fibrous roots.

Structural roots showing blackening from waterlogged conditions.

Rootstock	Waterlogging/flooding tolerance	*Phytophthora* tolerance 1 = Best 5 = Worst	Salinity tolerance	Rootstock characteristics
Benton citrange	poor – intermediate	2	good	shallow rooted
Carrizo and Troyer citrange	poor – intermediate	2	poor	intermediate depth & fibrous
Rough lemon	intermediate – good	4	poor	deep rooted and extensive lateral growth
Sweet orange	poor	5	intermediate	intermediate depth
Swingle citrumelo	good	2	intermediate	intermediate depth
Trifoliata	intermediate-good	1 (highly resistant)	poor	shallow rooted & fibrous

Table 1: Citrus rootstock characteristics and tolerances

Diseases prevalent following wet conditions

A number of mostly fungal diseases can become a problem following wet weather or in conditions of high humidity. The most important of these is *Phytophthora* root rot, but in wet soils, other fungi may exacerbate injury to already damaged roots.

Phytophthora

The fungus *Phytophthora* causes three main diseases in citrus – root rot, collar rot and brown rot.

Root rot

Rootstocks vary in their tolerance to *Phytophthora* root rot. Trifoliata is highly resistant to the fungus, and the citrange rootstocks (Troyer, Carrizo, Benton) and Swingle citrumelo have good tolerance, whilst rough lemon and sweet orange are very susceptible. (see Table 1).

The *Phytophthora* fungus needs moisture to become active and when soil is dry its activity ceases. Temperature and soil pH can also influence activity. *Phytophthora* can thrive in moist soils with a pH of between 5.5 and 7.5. If the fungus is present and soil moisture is high, fibrous roots can be destroyed in a few days and root replacement may not be sufficient to maintain tree health. If the soil is wet for lengthy periods the permanent lateral and larger roots can be infected.

The above ground symptoms of *Phytophthora* root rot include thinning of the foliage (usually starting at the tops of trees), sparse new growth and reduced tree vigour, yellowing, dull or bronzed foliage, yellow veins and dieback of twigs and branches. *Phytophthora* affected trees which are suffering root damage, require lighter more frequent irrigations than healthy trees.

Using phosphorous acid to contol root rot

The only chemical registered for the control of *Phytophthora* root rot in citrus is phosphorous acid applied as a foliar spray. Phosphorous acid (also referred to as phosphonic acid or phosphonate) protects roots against the *Phytophthora* fungus, so trees need to have some healthy roots for it to be effective. Phosphorous acid does not reduce populations of *Phytophthora* in the soil, but has a dual action in the plant — it directly inhibits the growth of the fungus and indirectly stimulates the plants natural defence mechanisms.

Phosphorous acid is highly systemic and mobile, but regardless of application method it moves with the sap flow to that part of the plant most actively growing. "Its movement in the tree is related to photoassimilate/carbohydrate partitioning which varies with the activity of the competing sinks, i.e. roots, leaves, fruit". (Wolstenholme 2010). Therefore application timing for phosphorous acid sprays is very important and needs to occur when there will be effective translocation from the leaves to the roots. When trees

Rootstocks vary in their tolerance to Phytophthora root rot. Rough lemon (on left) which is very susceptible, showing symptoms of dieback compared to healthy trees on trifoliata (right) which is highly resistant to Phytophthora root rot.

are flowering and setting fruit or when vegetative growth is vigorous, these organs have a stronger need for carbohydrates than the roots. If phosphorous acid is applied at these times it may remain largely in the leaves and not move quickly down into the roots to provide protection from *Phytophthora* root rot . Based on this information, application timing in citrus would be best targeted after any leaf flush has finished. For this reason most product labels recommend applications in either autumn or late winter prior to flowering or any growth flush. For foliar application good leaf cover is necessary.

Most research on the use of phosphorous acid to control *Phytophthora* has been carried out on avocados. This research has shown for foliar application of phosphorous acid that:

- High volume sprays applied to the point of runoff was the most effective application method at increasing phosphonic acid levels in the roots (Thomas 2001).
- Phytotoxicity (leaf burn) was related to the pH of the formulation applied. Therefore it should not be mixed with other chemicals and the pH of the final tank mixture should be as close as possible to 7.2 (Whiley *et al* 2001).
- The presence of some copper residues (particularly copper hydroxide) on the leaf increased the risk of phytotoxicity. (Whiley *et al* 2001).

Research on citrus has also shown that foliar application of phosphorous acid can cause some phytotoxic effects (e.g. leaf burn) in young mandarin trees (container grown and field planted). Most product labels carry warning statements about this and lower rates are usually recommended for young trees.

Most product labels also commonly carry the following critical comments *"for effective control apply as a protectant, before above ground symptoms of decline or collar rot become evident. Phosphorous acid should not be applied under high temperatures (>35°C) particularly if humidity is low or to moisture stressed trees".*

For best results and to avoid problems with phytotoxicity follow all label directions carefully.

A build up of soil from ant activity, hidden behind the tree guard has led to collar rot.

Superficial paring of the bark showing symptoms of dieback from collar rot.

Collar rot

Spores of the Phytophthora fungus are produced in organic matter on the soil surface and are splashed or carried onto tree trunks causing collar rot. Trees on trifoliata rootstock will only develop symptoms on the scion as trifoliata is largely resistant to collar rot. Ensuring the bud-union is well above soil level is generally the most effective way of preventing collar rot. Scions vary in their susceptibility to collar rot with lemons being the most susceptible, followed by grapefruit, Washington navel and Valencia orange.

Inspection of the trunks at various intervals following flooding is important. The first indication of collar rot is the exudation of gum on the trunk. Superficial paring of the bark with a sharp knife, in the vicinity of the gumming will show the bark to be discoloured and moist, later becoming dead, dry and brittle. Infection most commonly starts near soil level and works its way upwards and around the trunk. However, after a flood, damage can occur anywhere on the trunk and branches where the muddy water reached. Trees may be attacked at all ages, but in mature trees the resulting foliar symptoms may not be evident until the disease has almost ring barked the trunk. Sometimes the infection dies out naturally due to dry weather conditions and a callus layer forms around the lesion. The lesion can also be invaded and enlarged by various wood rotting fungi.

Also check the trunks of young trees that still have tree guards or wraps in place. Soil can be carried up the trunk by ants or flood water and become trapped behind the guards — bringing infected soil into contact with the tree trunk, causing collar rot. Remove the trunk guards and any soil present and apply a protectant copper spray to the tree trunk.

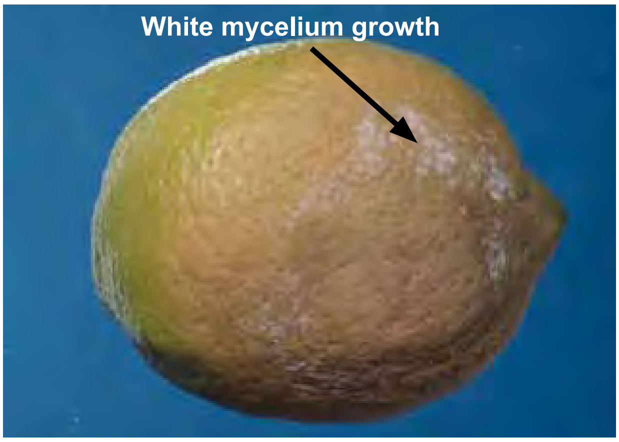
On older trees prune any low hanging branches to a height of 45–50 cm above the soil and remove weeds close to the butt to help improve air circulation and reduce collar rot. Spraying the bark at the base of the trunk with a protectant fungicide such as copper may help prevent infection.

Young tree death from collar rot which was hidden from view behind the tree guard.

Brown rot

Any fallen fruit or low hanging fruit is especially prone to coming in contact with water or water splash carrying the *Phytophthora* fungus. Insects and snails can also carry spores and infect fruit higher in the tree. It is usually fruit which are starting to colour or have coloured which are most susceptible to brown rot. Infected fruit will usually drop. The application of a copper spray particularly to the skirts of trees will protect low hanging fruit from brown rot infection. Do not harvest fallen fruit.

Well-timed copper sprays will also control Septoria and greasy spots, diseases which could also be exacerbated by the recent rains and resulting humid conditions. A copper spray is normally recommended for control of these diseases in March–April in southern growing regions.



Brown rot symptoms on lemon fruit showing white mycelium growth around the edge of infection.

Fruit on the lower branches of trees are very susceptible to infection from brown rot, leading to fruit fall.

Sudden Death

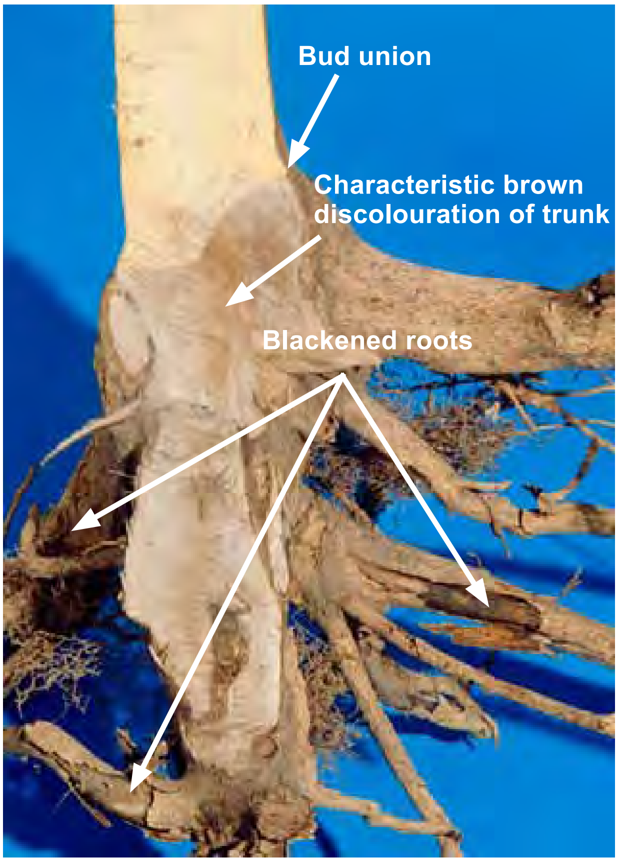
Sudden death is associated with poorly drained soil which has been subject to periods of temporary waterlogging and anaerobic conditions. Affected trees often wilt and die suddenly, usually with the leaves and fruit still attached. Progress of the disease can be less dramatic with a slow down in tree growth or the tree may be unthrifty for some time prior to sudden collapse, often just before fruit are ready to harvest. Affected trees always show one or more dead blackened structural roots from which a characteristic dry brown discoloration extends into and across the butt but not beyond the bud-union. The discoloured wood often has the smell of rancid coconut oil. Fruiting bodies of the ink cap fungus (*Coprinus*) are sometimes seen at the base of trees especially in autumn and are indicative of dead roots and high ammonium levels.

Sudden death affects trees of all scion varieties, but predominantly those on trifoliata and Carrizo and Troyer citrange rootstocks. Trees of all ages have succumbed to the disorder, but the incidence is greatest in 7 to 15 year old trees. Sudden death occurs predominantly on heavier soils or where drainage problems exist, due to perched water tables and/or compacted layers in the subsoil. Intermittent periods of waterlogging and poor aeration lead to a weakening of the root system and deterioration of root health. The incidence of sudden death may increase in the months and years to come as a result of the recent heavy rainfall and flooding events.

A major research project looking at the cause of sudden death in citrus was undertaken by Raquel Shearman in the MIA. Findings from that work indicated that where sudden death was occurring, citrus was being produced in sub-optimal soil conditions. Blocks affected by sudden death had heavier soil textures (medium to heavy clay top soils), duller soil colours and more mottling and manganese nodules — indicating the soils were subject to temporary waterlogging or poor soil aeration. In 10 orchards studied in the Griffith area the average incidence of sudden death was 24%

Sudden death causes trees to suddenly die, usually with their fruit and leaves still attached.

and affected trees tended to occur in clusters or defined areas, rather than randomly throughout a block. The subsoil of sudden death affected blocks was wetter and less aerated and soil compaction was evident. Although some roots penetrated through this compacted layer, it was still causing poor internal drainage, leading to intermittent waterlogging (from perched water tables) resulting in anaerobic soil conditions. Table 2 summarises some of the soil characteristics from the healthy and sudden death affected sites studied.



Transection of sudden death affected root system, showing the brown discolouration entering from the rotting roots, and ceasing at the bud union.

What can be done after flooding & waterlogging?

Short term:

- If possible dig surface drains or trenches to help direct water quickly away from trees or low lying areas.
- Do not take heavy machinery onto soils which are waterlogged as this will cause further compaction and structural damage to soil, exasperating drainage problems.
- On young trees check inside tree guards for any build up of soil, ants and the presence of collar rot. Remove tree guards, clean away soil and apply a protectant copper spray.
- Check the trunks of mature trees for signs of collar rot, remove any soil and tall growing weeds away from trunks and skirt low hanging branches. Ensure the bud union is well above soil level. Apply a protective copper spray to the trunks including above the bud union.
- If trees are suffering from Phytophthora root rot – foliar sprays of phosphorous acid can be applied. Remember trees need good foliage cover and an adequate amount of healthy roots for the phosphorous acid to move into the root system and provide protection against attack. The best timing is when the roots are actively growing, after any major shoot flush is finished. For more details see page 4.
- To prevent brown rot on fruit, skirt low hanging branches and apply a protectant copper spray to tree skirts.
- If trees are suffering root damage or root rot reduce irrigation and fertiliser amounts accordingly. Trees suffering root damage require lighter more frequent irrigations. Monitor soil moisture levels using devices such as tensiometers or gypsum blocks.

	Healthy sites	Sudden Death sites
Soil pit description	Soils dark reddish brown with only a few reddish yellow mottles. Soil colour shows no visual symptoms of previous waterlogging events.	Soils paler and duller in colour especially in the subsoil with frequent red, yellow and orange mottles. Soil colour shows evidence of previous waterlogging events, iron re-oxidation and poor soil aeration.
Soil texture	Clay loam to light clay topsoil	Medium to heavy clay topsoil
Porosity (air/water)		Wetter & less aerated in the root zone. Pores become filled with water after rainfall or irrigation and do not drain, with subsoil becoming anaerobic.
Soil compaction		Contributing to poor internal drainage of soil profile, leading to waterlogging through perched water tables.
Soil chemical factors	Nitrate higher	Ammonium and nitrite nitrogen higher.

Table 2: Description of soils from sudden death and healthy sites. (Shearman, 2006)

- Monitor foliage for signs of any nutrient toxicities or deficiencies and adjust fertiliser programs to suit.
- In southern growing regions a protectant copper spray applied in March–April will help manage brown rot, Septoria and greasy spots, diseases which could be exacerbated by the recent rains and resulting humid conditions.

Long term:

- Prior to planting any new blocks, carefully assess local soil conditions by undertaking a soil survey and digging soil pits across the site – don't plant trees in soils or sites that are unsuitable for growing citrus – citrus trees require good drainage.
- Before you plant – undertake all measures necessary that will help mitigate any future soil waterlogging problems such as the installation of subsurface tile and mole drains and the use of mounds in tree rows.
- Select rootstocks that match local soil conditions.
- When planting trees ensure the bud union is well above soil level.
- Match your irrigation system to local soil conditions – design your system so that you can deliver different amounts of water to match different soil conditions within your farm or block.
- Don't over irrigate – monitor soil moisture levels in the topsoil and subsoil using monitoring tools such as tensiometers or gypsum blocks. For example tensiometers should be positioned at depths of 30 and 60 cm in the tree row.

Always read the label: Users of agricultural (or veterinary) chemical products must always read the label and any Permit before using the product, and strictly comply with the directions on the label and the conditions of any Permit. Users are not absolved from compliance with the directions on the label or the conditions of the Permit by reason of any statement made or not made in this publication.

Further reading

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